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THESIS

EVALUATION OF FIRE SUPPORT RESPONSIVENESS

IN THE MAGTF C4I CONCEPT

by

Bienvenido P. Intoy

September 1995

Thesis Advisor: William G. Kemple

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13. ABSTRACT *(maximum 200 words)*
The United States Marine Corps (USMC) is developing and fielding command and control (C2) tactical data systems (TDS) to improve the warfighting capability of the Marine Air-Ground Task Force (MAGTF). To meet the increased communication requirements created by the C2 systems, the Marine Corps is developing the Tactical Data Network (TDN). The MAGTF Command, Control, Communications, Computers, and Intelligence (C4I) concept integrates the TDN and the C2 tactical data systems. This thesis evaluates the responsiveness of fire support available to maneuver commanders in the MAGTF C4I concept. The evaluation is accomplished by designing and implementing a simulation model of the ground fire support network for an infantry regiment with three infantry battalions and an artillery battalion in support. To evaluate fire support responsiveness, the average system response times are measured under different transmission rates and number of conduct of fire (COF) nets in the artillery battalion. The analysis technique employs graphical, parametric, and non-parametric statistical methods to test for significant differences in system response times under different conditions. Conclusions state a significant improvement in the responsiveness of fire support available to maneuver commanders in the MAGTF C4I concept. Recommendations stress the necessity to develop appropriate techniques and procedures for digital operations, to continue the existing efforts in using simulation modeling for proposed C2 systems, and to begin collecting data for future modeling and simulation during field operations where fielded C2 systems are employed.

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EVALUATION OF FIRE SUPPORT RESPONSIVENESS
IN THE MAGTF C4I CONCEPT

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Submitted in partial fulfillment of the
requirements for the degree of

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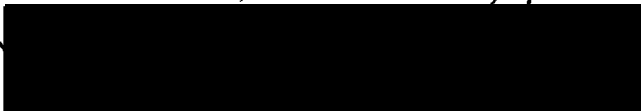
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ABSTRACT

The United States Marine Corps (USMC) is developing and fielding command and control (C2) Tactical Data Systems (TDS) to improve the warfighting capability of the Marine Air-Ground Task Force (MAGTF). To meet the increased communication requirements created by the C2 systems, the Marine Corps is developing the Tactical Data Network (TDN). The MAGTF Command, Control, Communications, Computers, and Intelligence (C4I) concept integrates the TDN and the C2 Tactical Data Systems. This thesis evaluates the responsiveness of fire support available to maneuver commanders in the MAGTF C4I concept. The evaluation is accomplished by designing and implementing a simulation model of the ground fire support network for an infantry regiment with three infantry battalions and an artillery battalion in support. To evaluate fire support responsiveness, the average system response times are measured under different transmission rates and number of conduct of fire (COF) nets in the artillery battalion. The analysis technique employs graphical, parametric, and non-parametric statistical methods to test for significant differences in system response times under different conditions. Conclusions state a significant improvement in the responsiveness of fire support available to maneuver commanders in the MAGTF C4I concept. Recommendations stress the necessity to develop appropriate techniques and procedures for digital operations, to continue the existing efforts in using simulation modeling for proposed C2 systems, and to begin collecting data for future modeling and simulation during field operations where fielded C2 systems are employed.

THESIS DISCLAIMER

The reader is cautioned that the computer program developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure the program is free of computational and logic errors, it cannot be considered validated. Any application of this program without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

Effective command and control is a force multiplier which is crucial to the success of a Marine Air-Ground Task Force (MAGTF). Present MAGTF commanders face unprecedented challenges in exercising command and control on the modern battlefield. The tempo of operations has increased, the MAGTF's area of interest has expanded, and more data is available to support tactical decision making. To assist MAGTF commanders in handling the large volume of information required for decision making and to improve the warfighting capability of forces, the Marine Corps is developing and fielding command and control Tactical Data Systems (TDS).

These systems provide a much greater volume of sensing and reporting information than current systems. To meet the increased communications requirements thus created by the command and control systems the Marine Corps is developing the Tactical Data Network (TDN). The TDN is a system of data communications gateways and servers interconnected with one another and their subscribers via a combination of local area networks, multi-channel communications, single channel radios, and switching systems. It will augment the existing MAGTF communications infrastructure and provide a communications backbone for the C2 Tactical Data Systems.

The MAGTF Command, Control, Communications, Computers, and Intelligence (C4I) concept integrates the Tactical Data Network and the C2 Tactical Data Systems. Implementation of the MAGTF C4I concept will transform the Marine Corps communications architecture into a system capable of automatically routing digital

message traffic through information pipelines that connect various elements of the MAGTF.

This thesis evaluates the responsiveness of fire support available to maneuver commanders in the MAGTF C4I concept. This evaluation was accomplished by designing and implementing a simulation model using COMNET III, a commercial simulation package. For manageability, analysis is limited to the ground fire support network for an infantry regiment consisting of three infantry battalions and an artillery battalion providing direct artillery support.

To evaluate fire support responsiveness, the average system response times are measured under different transmission rates and number of conduct of fire (COF) nets in the artillery battalion. The system response time is measured in the model by the elapsed time from when a forward observer transmits a fire mission (the stimulus) until a "shot" (the response) is received by the forward observer from the firing artillery battery. The analysis technique employs graphical, parametric, and non-parametric statistical methods to test for significant differences in average system response times under different conditions.

This thesis found a significant improvement in the responsiveness of fire support available to maneuver commanders under the MAGTF C4I concept. Recommendations stress the necessity to develop appropriate techniques and procedures for digital operations, to continue the existing efforts in using simulation modeling for proposed C2

systems, and to begin collecting data for future modeling and simulation during field

operations where C2 Tactical Data Systems are employed.

I. INTRODUCTION

A. PROBLEM STATEMENT

Effective command and control is a force multiplier which is crucial to the success of a Marine Air-Ground Task Force (MAGTF). Command and control (C2) is the exercise of authority and direction by a commander, over assigned forces, in the accomplishment of the mission. It is performed through an arrangement of personnel, equipment, communications facilities, and procedures employed by a commander in planning, directing, coordinating and controlling forces and operations in the accomplishment of the mission. Done well, command and control can bring success, even against otherwise superior forces. [Ref. 1: p. 14]

Present MAGTF commanders face unprecedented challenges in exercising command and control on the modern battlefield. The tempo of operations has increased, the MAGTF's area of interest has expanded, and more data is available to support tactical decision making. To assist MAGTF commanders in handling the large volume of information required for decision making, and to improve the warfighting capability of forces, the Marine Corps is developing and fielding C2 Tactical Data Systems (TDS) in the following functional areas: maneuver, intelligence, air operations, fire support, combat service support and C2 warfare. [Ref. 2: p. 4-3]

These systems provide a much greater volume of sensing and reporting information than current systems. To meet the increased communications requirements thus created by the command and control systems, the Marine Corps is developing the Tactical Data

Network (TDN). The TDN is a system of data communications gateways and servers interconnected with one another and their subscribers via a combination of local area networks, multi-channel communications, single channel radios, and switching systems. It will augment the existing MAGTF communications infrastructure and provide a communications backbone for the C2 Tactical Data Systems. [Ref. 3: p. 1-12]

The MAGTF Command, Control, Communications, Computers, and Intelligence (C4I) concept, formerly the Marine Tactical Automated Command and Control System (MTACCS), integrates the Tactical Data Network and the C2 Tactical Data Systems. The MAGTF C4I concept will provide MAGTF commanders with the means to manage the complexity of the modern battlefield. [Ref. 2: p. 3-3]

Implementation of the MAGTF C4I concept will transform the Marine Corps communications architecture into a system capable of automatically routing digital message traffic through information pipelines that connect various elements of the MAGTF, resulting in the reduction of dedicated nets and equipment required to support tactical operations. The evolution of the tactical communications architecture from dedicated nets to digital information pipelines raises the following question: Will the MAGTF C4I concept, the integration of the Tactical Data Network and the C2 Tactical Data Systems, significantly improve the responsiveness of fire support available to maneuver commanders?

B. PURPOSE AND SCOPE

The purpose of this thesis is to design and implement a simulation model to evaluate and compare the responsiveness of the current fire support communication architecture with the TDN communication architecture. For manageability, analysis will be limited to the ground fire support network for an infantry regiment consisting of three infantry battalions and an artillery battalion providing direct artillery support.

The current network will be evaluated using the Marine Corps Fire Support System (MCFSS) data communications architecture and its components. The Tactical Data Network communications architecture will be varied by combining the conduct of fire (COF) nets in the artillery battalion. Both architectures will transmit over the single channel ground and airborne radio system (SINCGARS).

Network traffic workload will be generated by fire support missions from the nine companies in the infantry regiment. Routing of the fire missions will be in accordance with the MCFSS Fire Support Coordination Center (FSCC) approval mode. [Ref. 4: p. 4-4]

The different communications architectures will be evaluated to examine the impact on responsiveness of support by combining and reducing nets at different transmission rates. Ultimately, it will be determined if the MAGTF C4I concept will significantly improve the responsiveness of fire support available to maneuver commanders.

C. OUTLINE OF THESIS CHAPTERS

The remainder of the thesis is organized as follows: Chapter II begins with a brief historical summary of C2 programs in the Marine Corps. This is followed by a description

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of the hardware and software components and communication nets in the MCFSS. The remainder of the chapter describes the C2 Tactical Data Systems and the TDN in the MAGTF C4I concept.

Chapter III explains how the MAGTF C4I concept and the MCFSS are incorporated into the models. It begins by explaining why simulation was chosen for the analysis and a brief discussion of the simulation environment. This is followed by a list of assumptions, an explanation of the C3 process in the models, and the measure used to compare the two communications architectures. The chapter concludes with an explanation of how the models were developed.

Chapter IV discusses the results of the simulation runs and explains the analysis performed on the output data. Model verification and validation is discussed in the beginning of the chapter and is followed by the presentation of simulation results. The remainder of the chapter explains the analysis performed on the generated data.

The problem in this thesis, "Will the MAGTF C4I concept, the integration of the Tactical Data Network and the C2 Tactical Data Systems, significantly improve the responsiveness of fire support available to maneuver commanders?" is answered in Chapter V. In closing, conclusions and recommendations about the MAGTF C4I concept are presented.

II. BACKGROUND INFORMATION

A. HISTORICAL SUMMARY

The Marine Corps has long realized the importance of automation for improving its command and control (C2) capabilities. C2 studies conducted in 1965 and 1966 resulted in the 1967 publication of the Marine Corps General Operational Requirements (GOR) Number CC-9 and the Marine Corps Tactical Command and Control Systems (MTACCS) concept. The MTACCS Master Plan was first published in 1976 and updated in 1981. The MTACCS concept sought to automate specific C2 functional areas using a series of integrated subsystems to support tactical operations. These functional areas included: maneuver, air operations, combat service support, fire support, and communications. In 1980, the C4 Systems Architecture Capstone was published to provide an overview of Marine Corps C4 plans and programs. This document provided policy for C4 programs, description and documentation of C4 programs, and methodology for the integration of C4 systems into a comprehensive architecture. [Ref. 2: p. 3-3]

While the Marine Corps was conducting C2 studies in the 1960s, the U.S. Army began fielding fire support C2 systems. In 1963, the Army fielded the Field Artillery Digital Automatic Computer (FADAC) which provided battery-center to center-of-target technical solutions. FADAC was followed by the equipment heavy Tactical Fire Direction System (TACFIRE) which automated tactical fire control. As technology developed in the 1980s, TACFIRE was subsequently ported into smaller computers and was referred to as Lightweight TACFIRE (LTACFIRE). [Ref. 4: p. 1-1]

During the period of 1983 to 1986, both the Congress and the General Accounting Office (GAO) took a specific interest in the standardization of fire support C2 systems in the Army and the Marine Corps. In 1987, the heightened interest in clarifying the need to have different systems and lack of support from the Marine Corps resulted in the termination of the Marine Integrated Fire and Air Support System (MIFASS), a key component of MTACCS. Termination of MIFASS resulted in the deliberate participation of the Marine Corps in the automated fire support systems being developed by the Army. In 1987, the Marine Corps initiated the Marine Flexible Fire Support System (FIREFLEX) testbed, using Lightweight TACFIRE and other off-the-shelf software and hardware to acquire knowledge and expertise in automated fire support systems. FIREFLEX was fielded in 1994 as the Marine Corps Fire Support System. [Ref. 4: p. 1-1]

B. MCFSS

The Marine Corps Fire Support System automates some fire support C2 by using digital systems and data communications to collect, process, and distribute information on the battlefield. It increases communications speed and accuracy without affecting command relationships or the doctrine, tactics, techniques and procedures for fire support.

1. MCFSS Components

MCFSS incorporates digital systems and data communications already employed by the Marine Corps. Figure 1, an illustration from FMFM 6-18-1, displays the communication nets and location of the following MCFSS components:

a. Digital Message System (DMS)

The AN/PSC-2A Digital Message System (DMS) is a lightweight handheld communications processor. It consists of the digital communications terminal (DCT) and a radio. The DCT will be eventually replaced by the digital automated communications terminal (DACT). [Ref. 4: p. 29]

b. Lightweight Computer Unit (LCU)

The AN/GYK-37 Lightweight Computer Unit is an 80486 processor based computer that serves as the hardware for two components. Loaded with Light TACFIRE software, it is referred to as the initial fire support automated system (IFSAS). IFSAS are located at the infantry headquarters' fire support coordination centers (FSCC). Loaded with the Battery Computer System (BCS) software, the LCU is used to automate technical fire direction at the artillery battery fire direction centers (FDC). [Ref. 4: p. 1-2]

c. Battlefield Computer Terminal (BCT)

The AN/GYG-1(V) Battlefield Computer Terminal (BCT) is used with Light TACFIRE software in fire direction centers (FDC) at the artillery battalion and regimental level. It provides the capability to receive, store, transmit, edit, display, and process fire support requests to facilitate fire support coordination. [Ref. 2: p. 4-D-2]

d. AN/TPQ-36 and AN/TMQ-31

The AN/TPQ-36 Firefinder Countermortar Radar and the AN/TMQ-31 Meteorological Data System (MDS) are located at the artillery regiment.
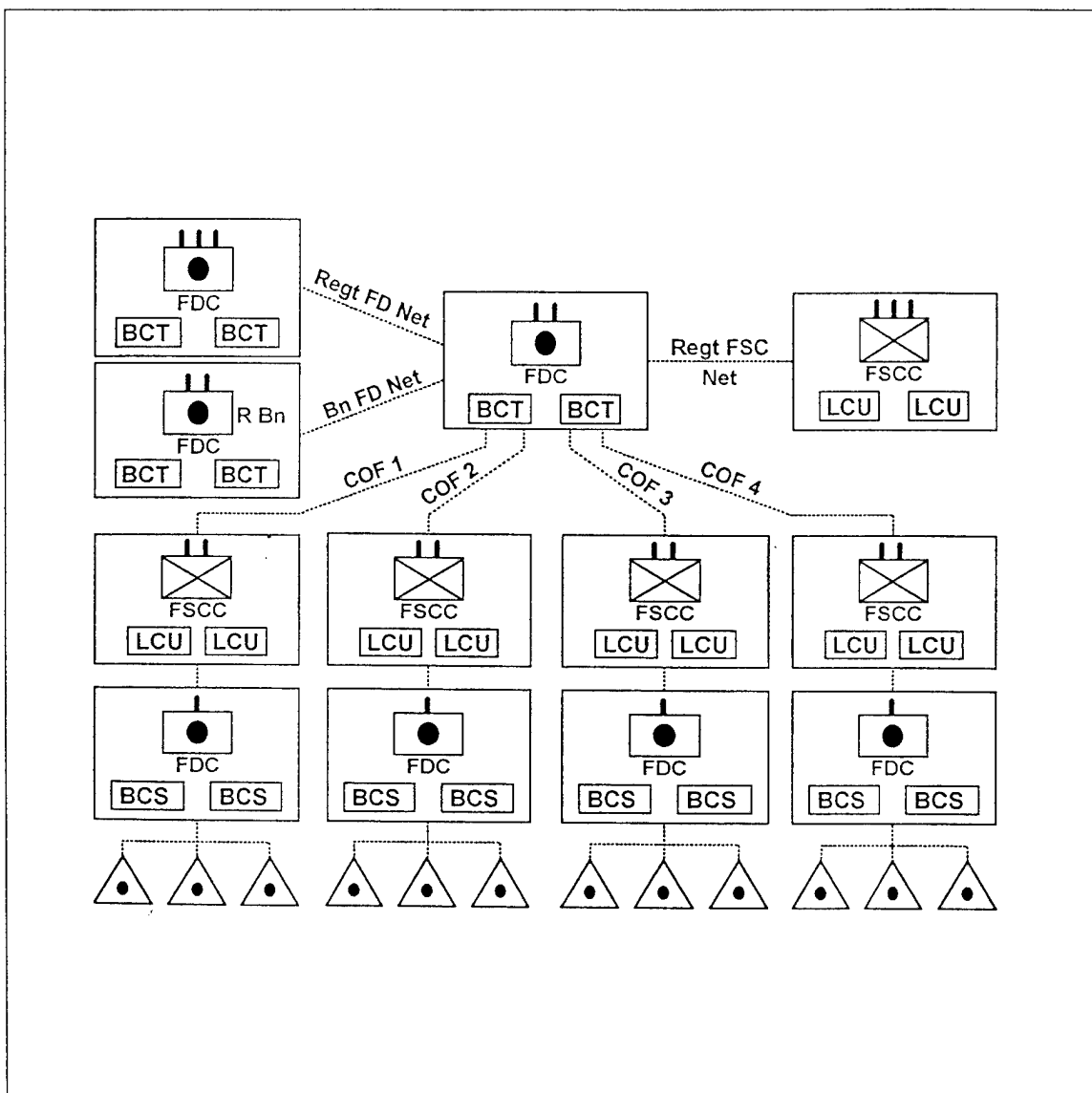
Figure 1. MCFSS Communications Nets

2. MCFSS Data Communications Nets

Reliable communications is a key factor in providing effective fire support to maneuver units. The MCFSS data communications nets provide data and voice communications capability. However, voice communications on the data nets are limited to establishing and reestablishing communications and when operations are degraded. The following, excerpted from MCFSS Techniques and Procedures (FMFM 6-18-1), are descriptions of fire support data communications nets used in the model.

a. Division Fire Support Coordination (FSC) Net

The division fire support coordination (DIV FSC) net provides a data net for fire support coordination and planning at the division level. It provides a means to disseminate tactical information and reports for all agencies of the division fire support coordination center (FSCC).

b. Artillery Regiment Fire Direction (RegtFD) Net

The artillery regiment fire direction (Regt FD) net is the primary link between the artillery regiment and its battalions. The net is used by the regiment to transmit orders, fire missions, tactical information, fire planning, and meteorological data to its battalions. The battalions use this net to request additional artillery support from the artillery regiment and to submit reports in data formats.

c. Infantry Regiment Fire Support Coordination (Regt FSC) Net

The infantry regimental fire support coordination (Regt FSC) net provides a means for exchanging tactical information between the infantry regiment, the infantry

battalion FSCCs, and the supporting artillery battalion FDC. Traffic related to fire support coordination and fire planning is passed over this net. The artillery battalion FDC and infantry battalion FSCCs, even though subscribers of this net, do not communicate with each other on this net. Communications between the artillery battalion FDC and infantry battalion FSCCs are accomplished on the conduct of fire nets (COF).

d. Artillery Battalion Conduct Of Fire (COF) Net

The artillery battalion conduct of fire (COF) nets are the primary means for artillery observers to conduct fire missions and provide tactical information to higher headquarters. The data COF net combines the function of the former voice COF and fire direction (FD) nets in the artillery battalion. One COF net is normally provided to each supported maneuver (infantry) battalion; however, two COF nets may be combined as dictated by the availability of communications equipment and the tactical situation.

e. Artillery Battalion Fire Direction (BnFD) Net

The artillery battalion fire direction net is an optional net and is activated if a direct link is required between the direct support battalion and its reinforcing battalion. The primary method of communications between the artillery battalion and its reinforcing battalion is the Regt FD net.

C. MAGTF C4I

In 1993, the name MTACCS was changed to Marine Air-Ground Task Force Command, Control, Communications, Computers, and Intelligence (MAGTF C4I) to accurately reflect the evolving nature and functionality of the system. The MAGTF C4I

concept is the integration of C2 Tactical Data Systems and communications (the TDN) to support tactical operations. This integration is intended to provide Marine commanders at all echelons a decisive edge over the enemy by having the capability to gather, process, store, and display tactical information, and issue operational orders faster and more efficiently than ever before. It achieves interoperability among these systems by utilizing common hardware, the Marine Common Hardware Suite (MCHS), and a standard set of system software, the Marine Common Applications Support Software (MCASS). [Ref. 2: p. 3-3]

1. MAGTF C4I Tactical Data Systems

The MAGTF C4I concept consists of tactical data systems, operable in garrison and deployed environments, in six C2 functional areas: maneuver, intelligence, air operations, fire support, combat service support, and C2 warfare. [Ref. 2: p. 4-3]

a. Maneuver Systems

The tactical combat operations (TCO) system will provide the commander with an integrated representation of the battlespace by receiving, fusing, selecting, and displaying information from C2 systems in other functional areas. Accurate position and velocity information of forces on the battlefield will be provided by the Precision Lightweight Global Positioning System Receiver (PLGR).

b. Intelligence Systems

Intelligence systems will automate the MAGTF intelligence activities of directing, collecting, processing, producing, and disseminating critical tactical intelligence.

They will also support the employment of reconnaissance, surveillance and target acquisition resources. They consist of the Intelligence Analysis System, Joint Service Imagery Processing System (JSIPS), Exdron Unmanned Aerial Vehicle (BQM-147A), Joint Tactical Unmanned Aerial Vehicle (JT-UAV), MAGTF Secondary Imagery Dissemination System (MAGTF SIDS), Team Portable COMINT System (TPCS), Tactical Receive Equipment (TRE), Tactical Remote Sensor System (TRSS), Tactical Remote Sensor System Airborne Relay, Tactical Remote Sensor System Day/Night Thermal Imager, and Technical Surveillance Countermeasures (TSCM).

c. *Air Operations Systems*

Air operations systems will provide flexible and responsive air support command and control. They will closely interface with fire support systems to plan and coordinate Navy and Marine Corps air combat operations. The systems will have the capability to interface with joint and combined forces air operations systems. They are the Advanced Tactical Air Command and Control Central (ATACC), Improved Direct Air Support Central, (IDASC), and Tactical Air Operations Module (TAOM).

d. *Fire Support Systems*

The automated C2 systems for fire support will be employed from the MAGTF command element down to the artillery forward observers. The Advanced Field Artillery Tactical Data System (AFATDS), the follow on system to MCFSS, is an integrated, battlefield management and decision support system. Hosted on a UNIX operating system, it overcomes the size, vulnerability, high sustainment cost, limited functionality,

central processing and training limitations of TACFIRE systems. It will be capable of managing artillery, air support, naval surface fire support, and mortar systems at all echelons of the MAGTF. [Ref. 5] AFATDS will reduce the time to clear and engage targets with its capability to display targets on a map background and to recommend the right fire support weapon system to engage the target. [Ref. 6: pp. 39-41]

e. Combat Service Support

Combat Service Support systems will ensure effective administrative and logistics planning and operations. The MAGTF C4I component in this functional area is the Marine Combat Service Support Command and Control (MCSSC2), formerly known as Marine Integrated Personnel System (MIPS)/Marine Integrated Logistics System (MILOGS).

f. Command and Control Warfare

The Command and Control Warfare system coordinates C2 and C2 protection actions in support of C2 warfare operations. It consists of the Radio Reconnaissance Distribution Device (R2D2), which provides single channel signals exploitation capabilities to the Radio Reconnaissance platoons.

2. Migration To Unified Build

To provide interoperability among C4I systems for joint and combined operations, while constrained by a shrinking defense budget, the Assistant Secretary of Defense for C3I has mandated migration to a single national standard called the Global Command and Control System (GCCS) Common Operating Environment (COE). The Marine Corps is

using the Navy's Joint Maritime Command Information System (JMCIS) as the vehicle for accomplishing this migration. JMCIS consists of common hardware and software called the Unified Build, which provides an environment, a set of developmental tools, documentation, and modules for building C4I systems. [Ref. 2: p. 3-8]

The Marine Corps is planning to transition as many programs as possible to GCCS COE. The following are MAGTF C4I systems recommended for transition to GCCS COE by the Marine Corps Systems Command (MARCORSYSCOM) Technical Strategy Working Group: Tactical Combat Operations (TCO), Intelligence Analysis System (IAS), Advanced Tactical Air Command Central (ATACC), Tactical Remote Sensor System (TRSS), and Team Portable COMINT System (TPCS). [Ref. 2: p. 3-9]

3. Tactical Data Network (TDN)

Successful implementation of the MAGTF C4I concept depends on fielding a communications architecture capable of meeting the increased communications requirements created by the C2 Tactical Data Systems. To meet these requirements, the Marine Corps is developing the Tactical Data Network (TDN) as part of the MAGTF C4I concept. The TDN will augment the existing communications infrastructure to provide the MAGTF an integrated, interoperable data network, forming the communications backbone for the tactical data systems. Using smart switching and on-demand routing to pass data traffic, the TDN will economize the existing communications bandwidth available to the MAGTF. [Ref. 3: p. 2-1]

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a. Definitions

The following discussion presents the terms and concepts necessary to form a basic understanding of C2 Tactical Data Systems and the TDN. The definitions are excerpts from the "*Marine Corps Tactical Systems Support Activity Quick Go Handbook*" and the "*First Marine Division's Communication SOP.*"

The tactical data systems in a C2 facility are linked through a local area network (LAN). A LAN consists of servers, computer workstations, printers, and other devices that are interconnected through a high speed transmission media such as coaxial or fiber-optic cable. A server is a computer processor that provides specific services such as routing of digital messages and file sharing in the LAN. The computer systems connected to the LAN communicate with each other using a common language or protocol. Protocols control how the network delivers a message from the source to a destination.

To send a digital message across an analog communication line or a single channel radio, it must go through a conversion device called a modem. The modem at the transmitting end modulates or converts digital signals from a computer; the modem at the receiving end demodulates the incoming signal, converting it back to its original format. The Marine Corps is currently using a modem called the Tactical Communications Interface Module (TCIM). It is an advanced modem that provides two programmable channels and supports a variety of protocols currently in use by the Marine Corps.

Messages are broken into small packets as they enter the LAN. Since there are multiple computer systems in the network, packets may collide if two or more devices

transmit simultaneously. To reduce this problem, the TDN will use a contention method called carrier sense multiple access with collision detection (CSMA/CD). Carrier sense stands for the capability of each component to detect traffic on the network. Multiple access allows all components to have equal access to the network without any predetermined transmission sequence. Collision detection is the capability for each computer system on the LAN to detect collisions with its data packets. CSMA without collision detection differs from CSMA with collision detection in that collisions are detected at the end of transmissions rather than at the instant when collision occurs. This means that there is wasted bandwidth on CSMA as the transmission duration is effectively lost.

MCFSS devices use TACFIRE protocol to communicate over single channel radios. The TACFIRE protocol is similar to CSMA without collision detection. AFATDS is using a protocol called AFATDS Variable Message Format (VMF). It allows all members of the net equivalent access, similar to CSMA. However, it can recognize and select the station with the highest message priority. Upon selection, the station selected is given a limited time to transmit. The process of priority selection starts all over once the allotted time has expired or the selected station has completed transmitting its entire message. AFATDS VMF is similar to a token ring contention method if all the messages have equal priority. In a token ring network, a token is passed to each station on the net in round robin order. The station with the token transmit packets during the token holding

time. Once the packets have been transmitted, or the token holding time expires, the token is passed to the next node.

If the destination of the message is outside the LAN, a decision is made by the server as to what transmission media to use. Transmission media available in the TDN are: coaxial or fiber optic cable connected to another LAN; multichannel radios providing full-duplex communications, which mean both ends of a circuit can transmit and receive simultaneously; and single-channel radios operating at half-duplex, where signals can only travel in one direction.

Once a transmission media has been selected, the signals are assigned to a circuit. There are three methods to assign signals to a particular circuit: packet switching, message switching, and circuit switching. Packet switching breaks each message into finite-size packets and adds the address of the destination and any required routing information, in addition to any error checking data. The message is reassembled into its original form once all packets are received in its destination. Circuit switching uses a switching system that selects and establishes a circuit for exclusive use between calling and called parties. The circuit is not available for use until the completion of message transmission and the connection is terminated. Message switching transmits entire messages to a destination once any circuit becomes available.

If the single channel radio is selected as the transmission media, the server sends the message to the TCIM for translation to a particular protocol and then to the radio. For TACFIRE and AFATDS VMF protocols, the messages are broken into packets and

sent to their destinations using a contention method described above. Selecting a multi-channel radio transmission media would result in routing the message through an automatic switching station where a dedicated circuit is established to transmit the message.

b. TDN System Description

The Tactical Data Network will consist of gateways, servers, and physical transmission systems (i.e., multi-channel and single channel radios, and cables). The gateway will be deployed at the Marine Expeditionary Force (MEF) or major subordinate command (MSC), with the server deployed down to the battalion/squadron level. The gateways and servers will perform electronic message handling and provide transparent routing of digital messages among LANs, the circuit switched network, and the single channel radio networks. [Ref. 4: p. 4-1]

As illustrated in Figure 2, the gateway will be the connection point between a MAGTF's internal data network and external networks operated by Joint Task Force (JTF) headquarters and other DOD agencies. It consists of the Marine Common Hardware Suite (MCHS) computers, communications security equipment, multi-protocol routers, LAN hubs, and other interfaces necessary for communications links. To achieve mobility, the gateway is contained in a High Mobility Multipurpose Wheeled Vehicle (HMMWV). [Ref. 3: p. 4-1]

The TDN Server is contained in three transit cases for transportability and provides typical LAN services such as file sharing and routing of digital messages. It

consists of multi-protocol routers, Marine Common Hardware Suite (MCHS) computers, communications security equipment, and other interfaces necessary for communication links. The Navy's Tactical Advanced Computer (TAC-4) with a Reduced Instruction Set Computing (RISC) based processor will be the MCHS computer/server. The server will have the processing and switching capacity, and connectivity required to support a standard LAN with up to forty-eight users (see Figure 3). [Ref. 1: p .4-1]
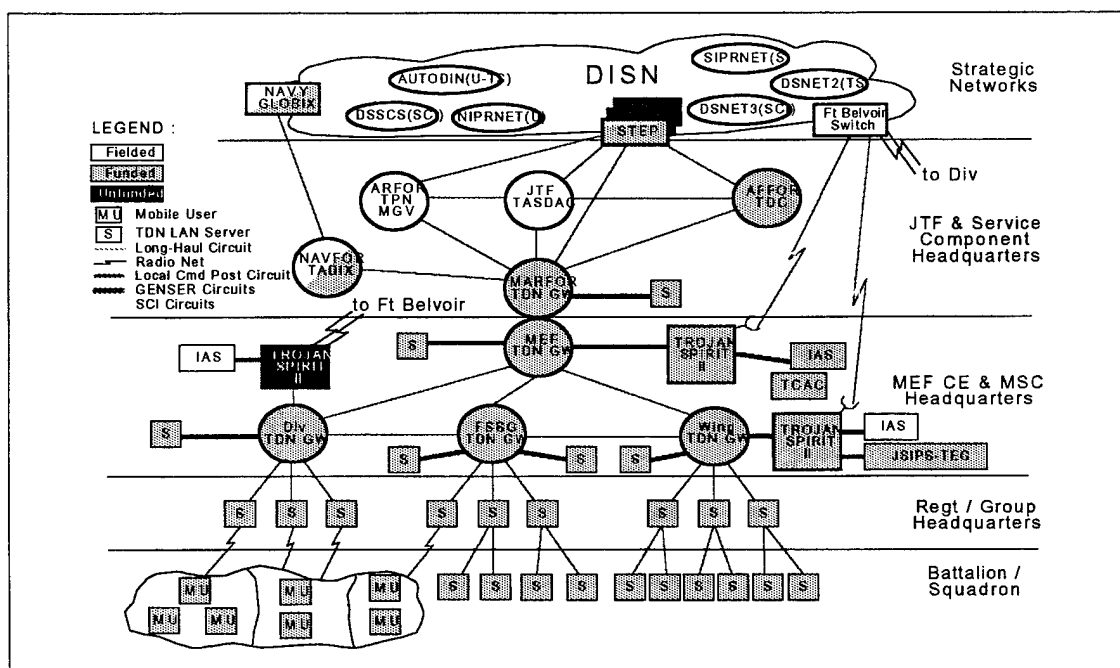
Figure 2. Tactical Data Network From Ref. [7].

Until Multi-Level Security (MLS) is implemented, the TDN will support three physically distinct LANs: a classified Top Secret General Services (GENSER) partition, a classified Secret GENSER partition, and a sensitive-but-unclassified partition. MLS will be provided in a future upgrade to the TDN at the gateway level through the implementation of the DOD's Multilevel Information Systems Security Initiative (MISSI)

plan. MISSI will provide a set of products that can be used to construct secure computer

networks and services in support of a wide variety of missions. [Ref. 3: p. 4-1]
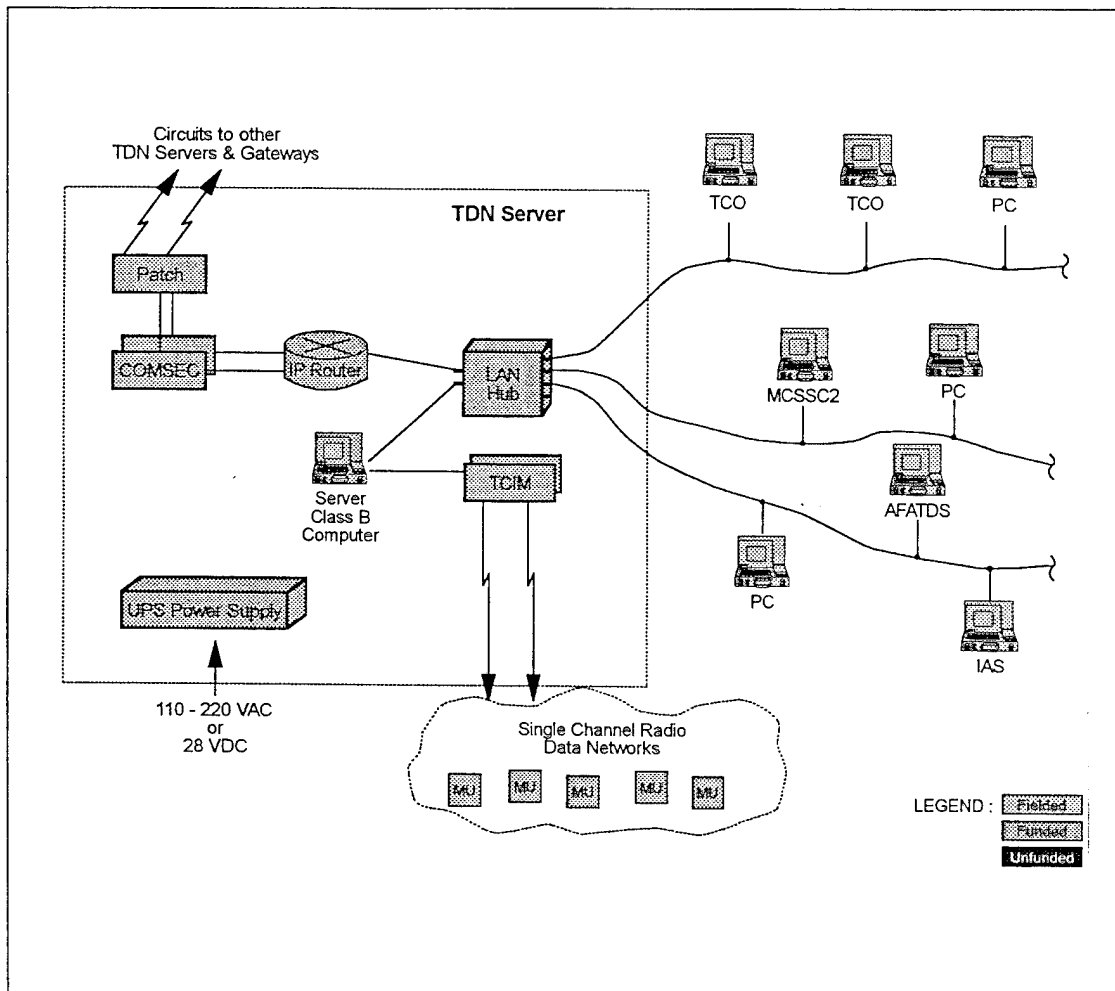
Figure 3. TDN Sever From Ref. [7].

III. METHODOLOGY

This chapter explains how the MAGTF C4I concept and the MCFSS were incorporated into the models. It begins by explaining why simulation was chosen for the analysis and a brief discussion of the simulation environment. This is followed by a list of assumptions, an explanation of the C3 process in the models, and the measure used to compare the two communications architectures. The chapter concludes with an explanation of how the models were developed.

A. WHY SIMULATION?

Modeling allows analysts to predict performance under different conditions and gain some insights into the cause and effect relationships among various components in a system. If the system is simple enough, an analytical solution can be obtained using a mathematical model. An analytical solution provides exact information on questions of interest. However, many systems are so complex that they cannot be solved analytically. These systems, including the C4I systems, are typically composed of a variety of subsystems that are difficult to model in mathematical terms. [Ref. 8: pp. 1-7]

The difficulties in analyzing these complex C4I systems by analytical methods often result in using simulation as an analysis tool. A simulation is "a technique that imitates the operation of a real-world system as it evolves over time." [Ref. 9: p. 1113] In simulation, the computer is used "to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristics of the model." [Ref. 8: p. 1] For this

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thesis, the simulation models of the TDN and the MCFSS communications architecture provide tools to easily alter the systems and evaluate them under different conditions.

B.   SIMULATION ENVIRONMENT

COMNET III, developed by CACI Products Company, was used to build the simulation models of the TDN and the MCFSS. It is a discrete event simulation model written in MODSIM II, a high-level, object-oriented simulation language. COMNET III, a special-purpose language designed to model computer and communications networks, allows the user to easily model a wide variety of network topologies and routing algorithms. These topologies include local area networks (LAN) and wide are networks (WAN) with circuit, message, or packet switching capability. Network components, such as computer workstations, routers, and transmission links of various protocols, are built into the package as generic objects. The parameters of the objects can be modified to represent a specific component in a particular network design.

COMNET III is available on most computer systems such as UNIX workstations and personal computers running Microsoft Windows, Microsoft Windows NT, and OS/2. The modeling and simulation of the MCFSS and the TDN were accomplished using 486 class IBM PC-compatible computers with Microsoft Windows.   It should be pointed out that COMNET III requires a minimum of 16 megabytes of random access memory (RAM).

C. ASSUMPTIONS

The following are assumptions about the simulation package and how the two communications architecture and their associated components were modeled.

1. COMNET III is a verified and validated network simulator (i.e., the software package performs discreet event simulations as intended and accurately represents local and wide area networks and their components).

2. The time to process a fire mission in the infantry FSCC and artillery FDCs is based on information contained in the Marine Corps Combat Readiness Evaluation System (MCCRES), Techniques and Procedures for Fire Support Coordination (FMFM 6-18), and telephone conversations with the IFSAS/MCFSS Branch at the Field Artillery School. The time delays are normally distributed with means and standard deviations listed in Table 1 (i.e., Normal (mean, standard deviation)).

3. Since all the messages are assigned equal priority in the TDN model, the token passing link protocol in COMNET III was selected to replicate the AFATDS VMF protocol.

4. The AFATDS version in the model is capable of technical fire direction in the battery fire direction center.

5. The carrier sense multiple access (CSMA) with no collision detection link protocol was selected to replicate the TACFIRE protocol for the MCFSS model.

6. Message length is based on information received from the Field Artillery Tactical Data Systems (FATDS) Field Office at the Magnavox Corporation.

D. MEASURES

Time is crucial in providing effective fire support to maneuver units. The Marine Corps Combat Readiness Evaluation System (MCCRES) measures readiness in artillery units by their response time to fire support request from supported maneuver units. Therefore, the measure of effectiveness selected is the system response time, which is defined as "the time delay between the moment when the C3 system receives a stimulus

and the moment it can deliver a response ." [Ref. 10: p. 528]

	Time Delays (seconds)
Infantry Bn FSCC	Normal (30,10)
Artillery Bn FDC	Normal (15, 15)
Artillery Btry FDC	Normal (45, 15)
Artillery Btry Gunline	Normal (25, 5)

Table 1. Distribution of Time Delays

The system response time is measured in the model by the elapsed time from when a forward observer transmits a fire mission (the stimulus) until a "shot" (the response) is received by the forward observer from the firing artillery battery. Measuring the total elapsed time in a COMNET III model is accomplished by using a "Filter Message Command" to suspend an application until a specific message, "shot", from the artillery battery, is received. The suspense time (i.e., the time that an application cannot execute other commands) of the application measures the total time delays to complete every stage of the process, the system response time.

E.   PROCESS DEFINITION

"The C3 process consists of the functions that must be performed by the C3 system to coordinate forces in the planning and execution of their mission." [Ref. 8: p. 35] In the artillery field, the process of providing responsive fire support to maneuver units requires precise and detailed fire mission procedures that are carried out by forward observers (FO) in the infantry companies up through the infantry and artillery regimental level.   The MCFSS Techniques and Procedures (FMFM 6-18-1) manual classifies the fire mission

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procedures into three modes of operation: the centralized mode, the Marine Expeditionary Unit (MEU) operations mode, and the FSCC approval mode.

In the centralized mode, the forward observer sends fire missions directly to the artillery battalion FDC. This mode can support either positive (i.e., each mission is cleared by the infantry FSCC) or passive (i.e., silence from the infantry FSCC is consent to fire) clearance of fire missions. The centralized mode is efficient in coordinating a low volume of fire missions. However, it places a heavier coordination burden on the artillery battalion FDC and is susceptible to fratricide in the passive mode. It is also unrealistic in situations where a forward observer equipped with a man packed radio is expected to communicate with the artillery battalion FDC that may be out of his communication range.

The MEU operations mode employs positive clearance and is only applicable to units with a maneuver battalion supported by a dedicated artillery battery. In this mode, the FO sends his fire missions to the infantry battalion FSCC. If the mission is cleared, it is routed directly to the artillery battery.

The FSCC approval mode is the most efficient for coordinating a high volume of fire missions. Thus, it is appropriate to use this mode in order to evaluate the responsiveness of the communications architecture in a regimental size force at peak message load. In the FSCC approval mode, the FO sends his fire missions directly to the infantry battalion FSCC. The FSCC clears each mission (i.e., positive clearance) and routes the mission to the artillery battalion fire direction center (FDC) for tactical fire direction. The battalion FDC processes the mission and determines which artillery battery to fire. Fire orders are

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transmitted to the appropriate firing battery and a message to observer (MTO) is sent to the forward observer via the infantry battalion FSCC. The artillery battery executes the fire order and reports "shot" and "rounds complete" to the battalion FDC and the forward observer. The forward observer observes the impact of the rounds and either ends the mission or makes subsequent corrections. If the forward observer decides to make corrections, the clearing process starts again. Ending the fire mission generates message of interests (MOI) to stations where the information is pertinent. For example, receipt of an end of mission message at the firing battery causes an automatic transmission of an ammunition count to the artillery battalion which sends it automatically to the infantry regimental FSCC. [Ref. 4: p. 4-4]

F. MODEL DEVELOPMENT

The stochastic models were created graphically using the generic objects provided in the COMNET III package. The parameters of the generic objects were modified to closely replicate the components of the MCFSS and the TDN. The communications architecture and parameter settings are based on information contained in the MCFSS Techniques and Procedures (FMFM 6-18-1), System Description for the TDN, and conversations with the Marine Corps Tactical Systems Support Activity (MCTSSA) TDN project officer. The unit organization in the models differs from FMFM 6-18-1's organization, Figure 1, of four infantry battalions and four artillery batteries. As shown in Figures 4 and 5, the models depict the current Marine Corps organization of three battalions per infantry regiment and three batteries per artillery battalion. The infantry

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Figure 4. Tactical Data Network (TDN) Model
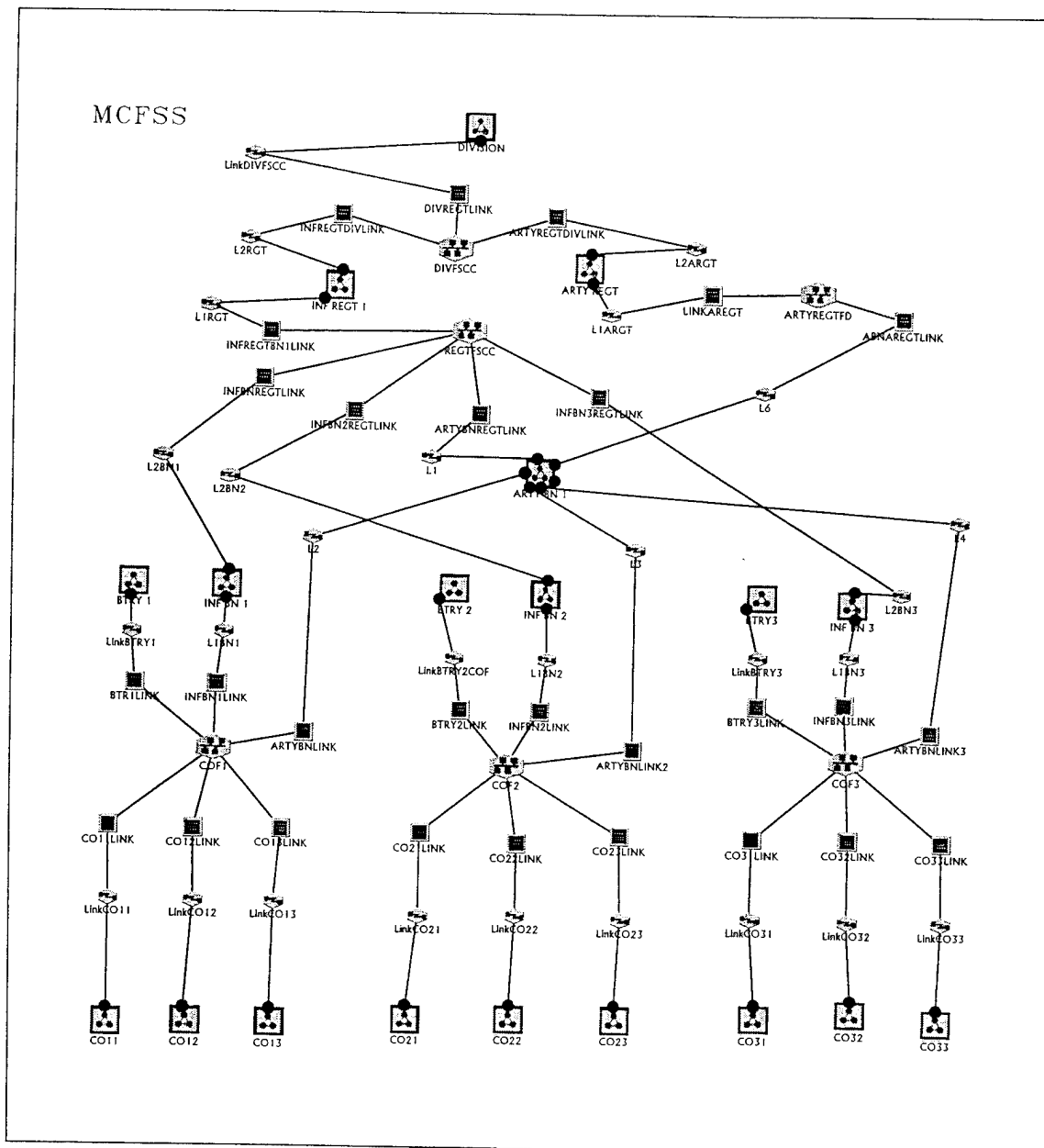
Figure 5. Marine Corps Fire Support System (MCFSS) Model

combat operations centers (COCs) and the artillery fire direction centers (FDCs) are shown in Appendix A.

The MCFSS and the TDN models used an identical stochastic workload to compare the responsiveness of both systems. The TDN performance objective requires the network to be able to receive, store, and transmit 3,000 to 12,000 messages in a twenty-four hour period. It also requires the TDN to be capable of managing peak loads occurring three times a day at two hour periods. [Ref. 3: p. 7-4]

Based on this information, a high volume of fire missions was scheduled to load the networks. A Poisson arrival pattern of fire missions was modeled using the exponential distribution with a mean of sixty seconds. The run length was set to six hours to replicate the total peak time of the TDN performance objective.

Nine variations of the models were created. As shown in Table 2, the transmission rates in bits per second (bps) and the numbers of nets in the artillery battalion were varied to evaluate and compare the responsiveness of both systems.

		Number Of COF Nets		
		1	2	3
D	1200 bps	COF 1	COF 1 + COF 2	COF1
a	(MCFSS)		COF 3	COF2
t				COF3
a	4800 bps	COF 1	COF 1 + COF 2	COF 1
	(TDN)		COF 3	COF 2
R				COF 3
a	8000 bps	COF 1	COF 1 + COF 2	COF 1
t	(TDN)		COF 3	COF 2
e				COF 3

Table 2. Model Variations

IV. OUTPUT ANALYSIS

This chapter discuss the results of the simulation runs and explains the analysis performed on the output data. Model verification and validation is discussed in the beginning of the chapter and is followed by the presentation of simulation results. The remainder of the chapter explains the analysis performed on the generated data.

A. MODEL VERIFICATION AND VALIDATION

1. Verification

"Verification is determining that a simulation computer program performs as intended, i.e., debugging the computer program." [Ref. 8: p. 299]   The objective in verifying the models is to ensure that the assumptions, the system components, and the process is properly implemented by COMNET III. The following are the four techniques used to verify the models [Ref. 8: p.302]:

1. The models were built using COMNET III, a proven and widely used package in the commercial industry.

2. Animation was used to confirm that the fire mission process (i.e., message flow and decision delay times) in the models is performed as intended. COMNET III provides concurrent animation which display the message flow while the simulation is running.

3. During the model development, a "trace" was used to provide a step-by-step screen print out of each event execution. Combined with the concurrent animation capability, the "trace" was effective in revealing problem areas.

4. As part of the evaluation, simulation results were obtained under a variety of conditions (i.e., different transmission rates and number of forward observers on the net). As shown in the analysis section, the output appear reasonable for different conditions.

2. Validation

"Validation is determining whether the simulation model "is an accurate representation of the system under study." [Ref. 8: p. 29] As discussed earlier, the TDN model simulates the components and the communications architecture of the MAGTF C4I concept. Since the concept has not been fully implemented, it is impossible to completely validate the model. However, the following steps were taken to partially validate the model:

1. Information about the existing and planned systems and communications architecture were obtained from the most recent documents and people who are knowledgeable in the specific area of interest.

2. The system response times from the model were shown to the USMC New Equipment Training Team at Ft.Sill. They commented that the system response times were reasonable for the assumed time delays shown in Table 1.

B. RESULTS

Table 3 summarizes the simulation results. It shows the number of replications and means for each of the nine model variations. The rows are categorize by transmission rates in bits per second (bps) and the columns by the number of conduct of fire (COF) nets in the artillery battalion.

Note that the second column of Table 3 has two types of nets: a net with six forward observers and a net with three forward observers. In this column, the overall mean and the means for the two types of net are listed separately. Separation of the data is done for the comparative analysis to be performed in the following section.

	1 COF Net (6 FOs per Net)	2 COF Nets (3 and 6 FOs per Net)	3 COF Nets (3 FOs per Net)

1200 bps	**A**
	Replications: 34
	Mean: 156,234 ms
		B
		Replications: 14
		Overall Mean: 152,804 ms
		6 FOs per Net
		    Mean : 153,478 ms
		3 FOs per Net
		    Mean: 151,455 ms
			C
			Replications: 12
			Mean: 152,364 ms
			Include Data from B
			    Mean: 152,110 ms

4800 bps	**D**
	Replications: 14
	Mean: 142,972 ms
		E
		Replications: 14
		Overall Mean: 135,789 ms
		6 FOs per Net
		    Mean: 137,625 ms
		3 FOs per Net
		    Mean: 132,116 ms
			F
			Replications: 13
			Mean: 132,246 ms
			Include Data from E
			    Mean: 132,201 ms

8000 bps	**G**
	Replications: 13
	Mean: 140,000
		H
		Replications: 19
		Overall Mean: 132,940 ms
		6 FOs per Net
		    Mean: 134,810 ms
		3 FOs per Net
		    Mean: 129,199 ms
			I
			Replications: 14
			Mean: 129,855 ms
			Include Data from H
			    Mean: 129,651

Table 3. Simulation Result

C. ANALYSIS

As stated in Chapter I, the purpose of this thesis is to design and implement a simulation model to answer the following question: Will the MAGTF C4I concept, the integration of the Tactical Data Network and C2 Tactical Data Systems, significantly improve the responsiveness of fire support available to maneuver commanders?

In order to answer this question, the average system response times will be analyzed to test for a significant difference between the current fire support system and the planned MAGTF C4I concept. This analysis will be conducted in five steps. The first phase of the analyses determines the layout of the data for the two-way analysis of variance (ANOVA). Once this is completed, an analysis of variance is performed to see if any interactions or significant differences exist between the levels of the two factors. Steps four and five complete the analysis by investigating the effects of transmission rates and numbers of COF nets on system response times.

Graphical and formal hypothesis testing methods are used to compare the system response times of the nine model variations. Box plots with 95% confidence interval boxes are used to graphically compare the medians of the system response times. Analysis of variance, the Mann-Whitney test, and the Kruskal-Wallis test are used to perform formal hypothesis testing. The analysis of variance, based on the assumption that the data are normally distributed with equal variance, will test for the null hypothesis of equal means. The results of these parametric tests are confirmed by the Mann-Whitney and

Kruskal-Wallis tests, which do not rely on the normality assumption. The results of the statistical tests are listed in Appendix B.

1. Comparison of Six and Three FOs Per Net Response Times

Operationally, the artillery battalion, working with two COF nets would have one net with three FOs who were attached to the infantry battalion that was expected to be the most heavily engaged, and one net with the six FOs attached to the other two infantry battalions. This configuration was used for the two COF nets variant of the model in order to model artillery battalions with one, two, and three COF nets. But, to reveal the differences in capabilities of the architectures, all FOs were heavily loaded. So, the modeled responsiveness should depend on the number of FOs per net, three, six, or nine. Thus, for analysis, it was decided to combine the data for the net with three FOs from the two COF variant (column two of Table 2) with that from the three FOs per net from the three COF variant. A preliminary analysis was conducted to ensure that:

1. The distributions for the three FOs per net and six FOs per net (column two of Table 2) within variant two were different.

2. The distributions for three FOs per net in variant two and three (columns two and three of Table 2) were not different.

Figure 6 shows the box plots of the system response times at 1200 bps categorized by the number of FOs per COF net. The overlap of the 95% confidence interval boxes does not reject the null hypothesis of equal medians with a 95% confidence. This is confirmed by the statistical tests which yields an attained significance level or p-value of 0.112 for the one way ANOVA and a p-value of 0.065 for the Mann-Whitney test. Thus, the null

hypothesis of equal means ($H_0 : \mu_3 = \mu_6$) between the three and six FOs per net response times cannot be rejected.

Figures 7 and 8 show the box plots of the 4800 and 8000 bps data. Since the 95% confidence interval boxes do not overlap, the difference between the medians are statistically significant at the .05 level. The results of the graphical analysis are confirmed by the one way ANOVA and the Mann-Whitney tests which yield p-values of zero for both transmission rates. Therefore, the null hypothesis of equal means between the three and six FOs per net response times are rejected at the 4800 and 8000 bps transmission rates.

2. Comparison of Three FOs Per Net Response Times

The purpose of this comparison is to test for a significant difference between the system response times of nets with three FOs in the two and three COF nets model variations (columns two and three of Table 3) at three levels of transmission rates. The three box plots of the response times (figures 9, 10, and 11) show an overlapping of the 95% confidence interval boxes. Thus, the null hypothesis of equal medians for the system response times in the COF nets with three FOs for the two and three COF net variations cannot be rejected with 95% confidence. These observations are confirmed by the attained significance levels from the ANOVA and Mann-Whitney tests. The p-values indicate that the null hypothesis of equal means between the two sets of response times cannot be rejected at.05 significance level.

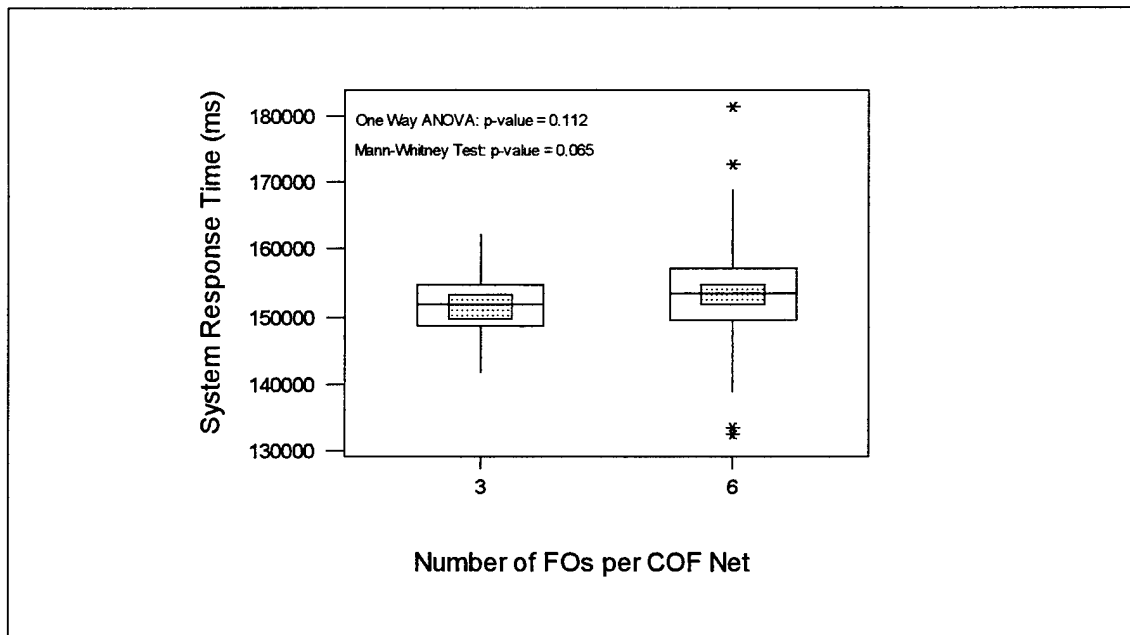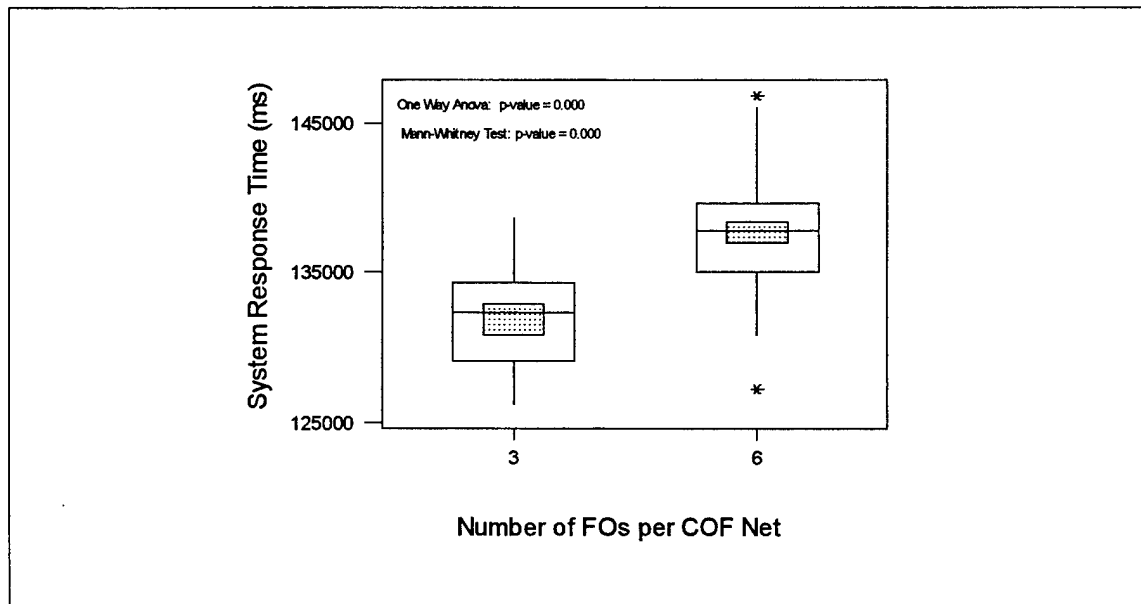**Figure 6. 1200 BPS System Response Time by Number Of FOs Per COF Net**

Figure 7. 4800 BPS System Response Time by Number Of FOs Per COF Net
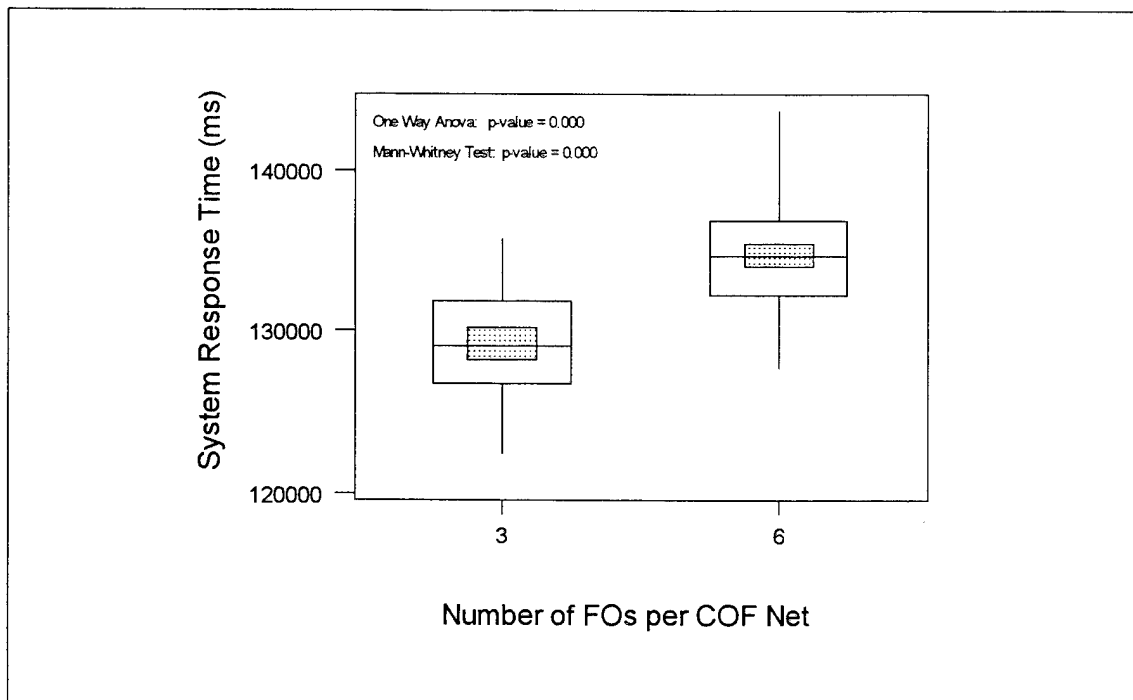
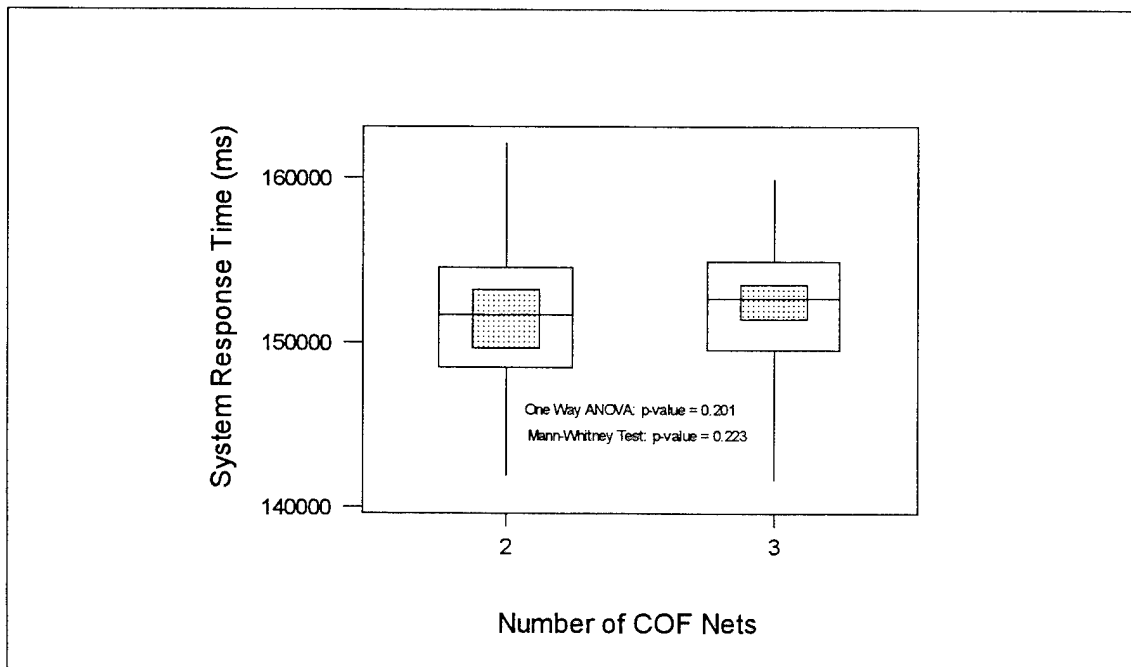**Figure 8. 8000 BPS System Response Time By Number Of FOs Per COF Net**

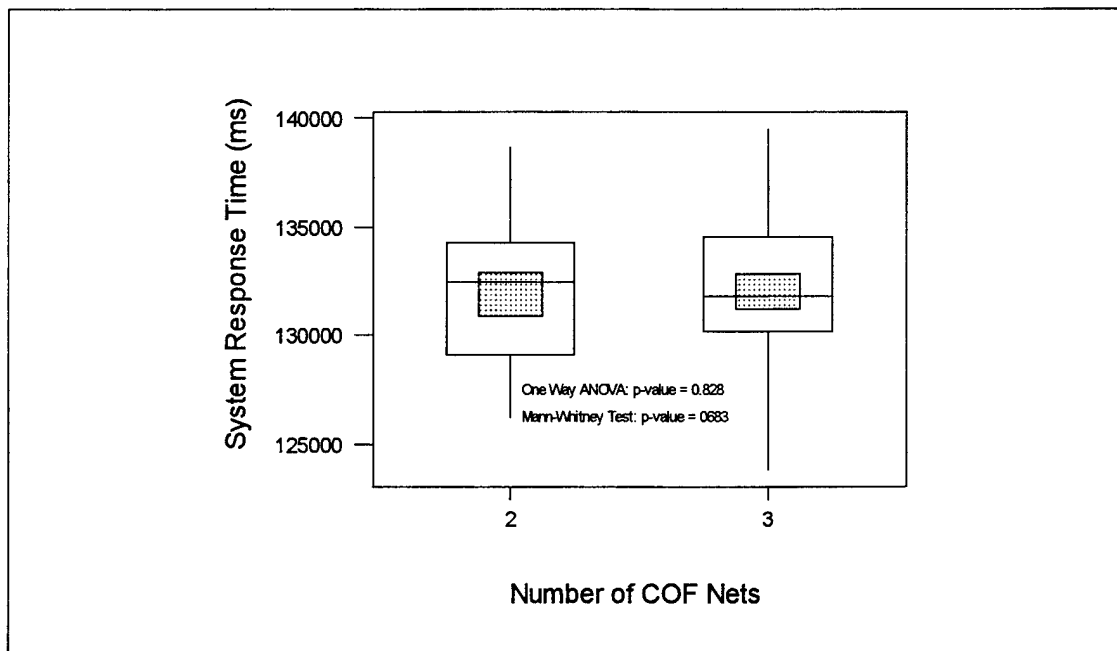**Figure 9. 1200 BPS System Response Time By Number Of COF Nets**

Figure 10. 4800 BPS System Response Time By Number Of COF Nets
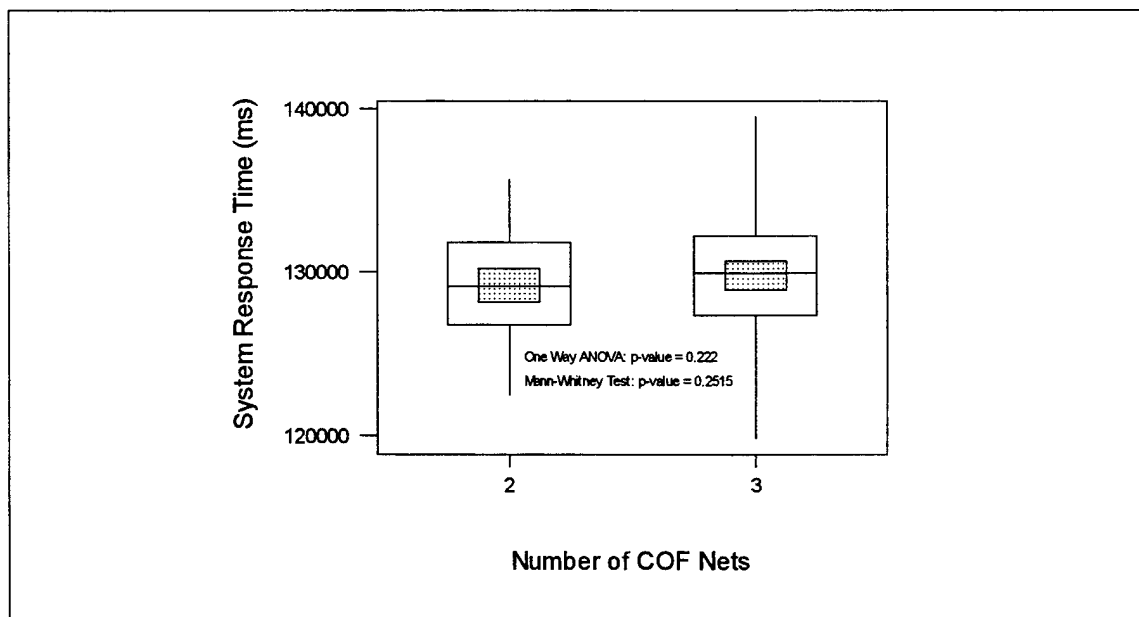

Figure 11. 8000 BPS System Response Time By Number Of COF Nets

3. Two-Way Analysis of Variance

The two-way ANOVA will test for significant effects and interactions of the two factors, the transmission rates and the number of COF nets. The layout for the unbalanced ANOVA is based on the analysis performed earlier. To summarize, step one of the analysis has shown that, with the exception of the 1200 bps net data, there is a significant difference between the six and the three FOs per net in the two COF nets model variation (column two of Table 3). Step two compared the two and three COF nets variations and found that there is no significant difference between system response times of nets with three FOs. Therefore, it is appropriate to combine the three FOs per net data in columns two and three of Table 3 for the two-way ANOVA.

The mathematical model for fixed effects two-way ANOVA with unbalanced observations is given by

$$y_{ijk} = \mu + \alpha_i + \beta_j + \delta_{ij} + \varepsilon_{ijk} \tag{1}$$

where

μ =   overall mean

α_i =   effects of different transmission rates

β_j =   effects of number of FOs per COF net

δ_{ij} =   interaction effects

ε_{ijk} =   errors

The three hypotheses to be tested under the present model are:

H_0': $\alpha_1 = \alpha_2 = \alpha_3 = 0$ against H_1': not all α_i are zero

H_0'': $\beta_1 = \beta_2 = \beta_3 = 0$ against H_1'': not all β_i are zero

H_0''': $\delta_{ij} = 0$ against H_1''': not all δ_{ij} are zero

Since the data generated by COMNET III were average system response times with different number of observations , the ANOVA performed was weighted to account for the different variances of the errors. The weights were calculated as the inverse of the number of observations for each averaged system response time. [Ref. 12: p. 83]

The results of the ANOVA show an attained significance level of 0.551 for the interactions between the transmission rate and the number of FOs per net. Thus, the null hypothesis of no significant interactions (i.e., H_0''': $\delta_{ij} = 0$) between the two factors cannot be rejected. This result agrees with the interactions plot in Figure 12.

Since the effects are found to be additive (i.e., no significant interactions), it is appropriate to test the significance of the main effects. The mathematical model without interactions is given by

$$y_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk} \tag{2}$$

The ANOVA for this model yield p-values of zero for the transmission rates and number of FOs per net which lead to rejection of the null hypotheses (i.e., H_0': $\alpha_1 = \alpha_2 = \alpha_3 = 0$ and H_0'': $\beta_1 = \beta_2 = \beta_3 = 0$) of equal effects for the different levels. These effects are apparent in equation three which list the mathematical model with its computed coefficients.

$y_{ijk} = 142{,}345 + 11{,}774$ I(1200 bps) - 4643 I(4800 bps) - 7,131 I(8000 bps)

$+ 3{,}305$ I(9 FOs per Net) + 333 I(2 FOs per Net) - 3,638 I(3 FOs per Net)   (3)

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where

I (level) = 1, if data collected at that level

0, otherwise

The main effects (Figure 13) plot and coefficients for the model indicate that the system response times at 1200 bps are significantly higher than those of 4800 and 8000 bps transmission rates. The effects of the number of FOs per net show that the system response times of artillery battalions with nine FOs per net are significantly higher than those of battalions with six or three FOs. These results will be further analyzed in steps 4 and 5.

The residual plots in Figure 14 show unusual values in the beginning of the observations and for observations with high system response times. Examination of the ANOVA layout and the means of the response times reveal that these values were generated by the 1200 bps model variation. These large residuals are the result of the wide range in the system response times of the 1200 bps model as the number of FOs are increased in the COF net.

4. Comparison of System Response Times by Number of FOs per COF Net

Figure 15 shows the box plots of all the response times categorized by the number of FOs per net. Since the 95% confidence interval boxes do not overlap, the null hypothesis of equal medians among the three response times is rejected. The p-values of zero from the statistical tests suggest that the number of FOs per COF net make a significant difference in the means of the system response times.
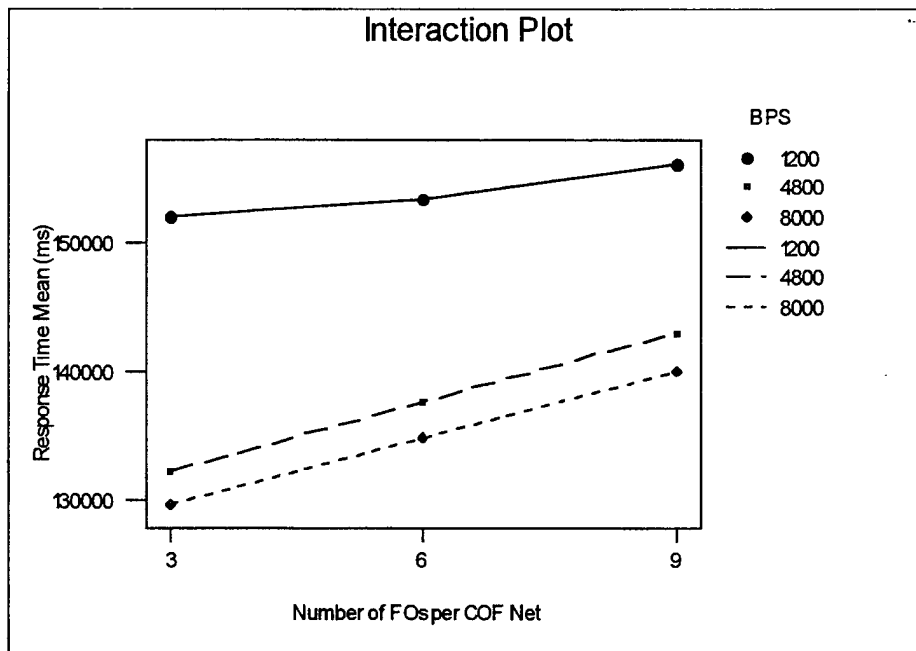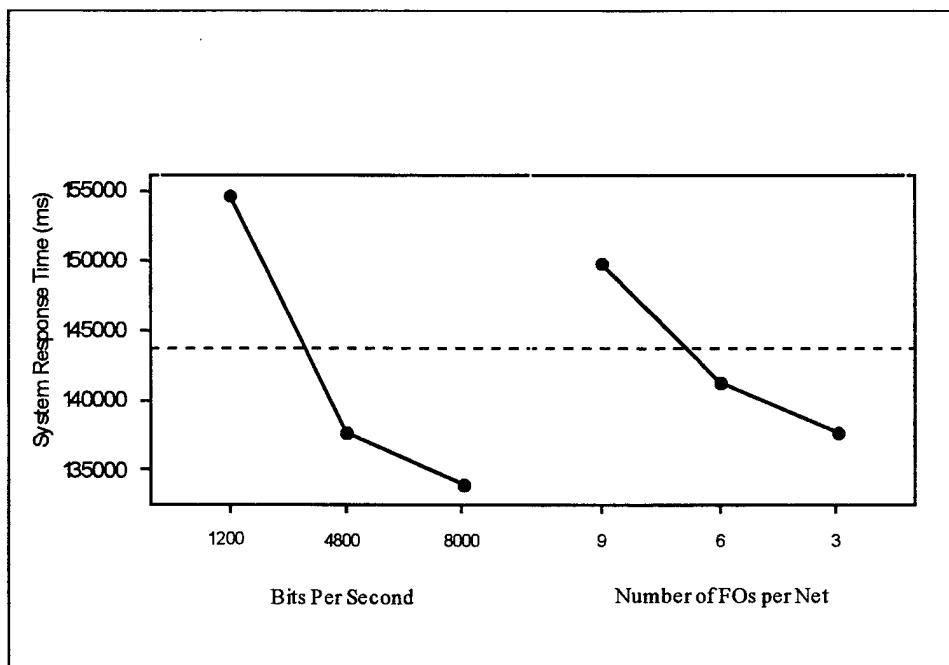
42

Figure 12. Interactions Plot

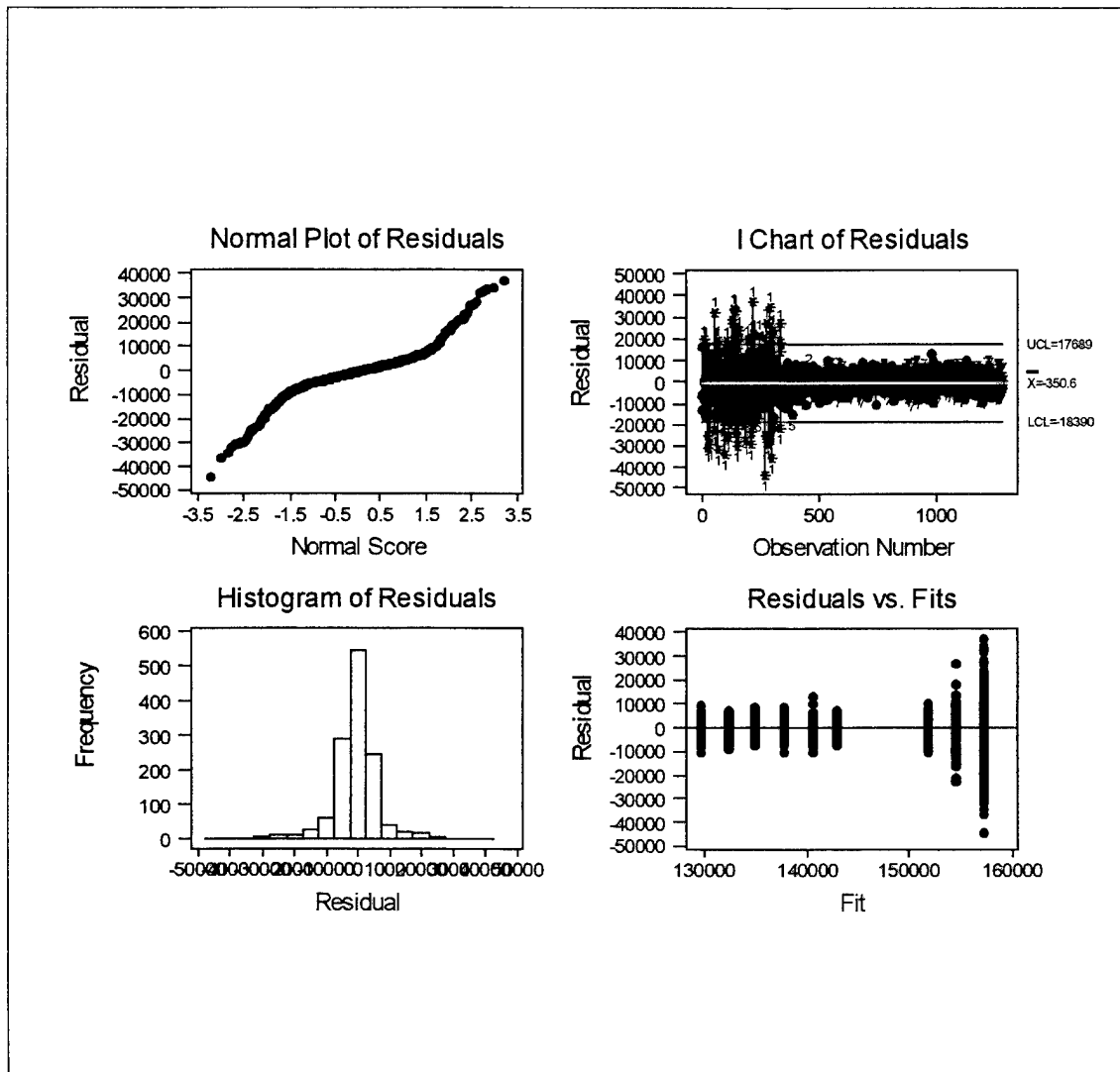**Figure 13. Main Effects Plot**

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Figure 14. Residual Plots

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Figure 16 shows the box plots for the 1200 bps system response times categorized by the number of FOs per net. In the 1200 bps, the one-way ANOVA and Kruskal -Wallis tests reject the hypothesis of equal means among the response times from the three model variations. However, a closer examination of the box plots show a gap between the 95% confidence interval boxes of the nine and three FO nets and an overlap of the 95% confidence interval boxes of the nine and six FOs per net data. Thus, there is a significant difference in medians of the nine and three FOs per net response times and no significant difference between the nine and six FOs per net data. This is confirmed by the 95% confidence interval for mean based on pooled standard deviation and Tukey's pairwise comparison shown in Appendix B.

Figures 17 and 18 show the box plots for the 4800 and 8000 bps transmission rates. The boxplots and the p-values of the statistical tests show a significant difference in the system response times for the three types of COF net. Additionally, figures 17 and 18 (4800 and 8000 bps transmission rate) show an apparent separation in the spread of the bulk (i.e., the central 50%) of the system response times in comparison to box plots in Figure 16 (1200 bps).

5. Comparison of System Response Time by Transmission Rates

Figure 19 shows the box plots of all the system response times by transmission rates. The non-ovelapping of the 95% confidence interval boxes and the p-values of zero from the statistical tests lead to the rejection of the null hypothesis of equal medians and means among the three transmission rates system response times.
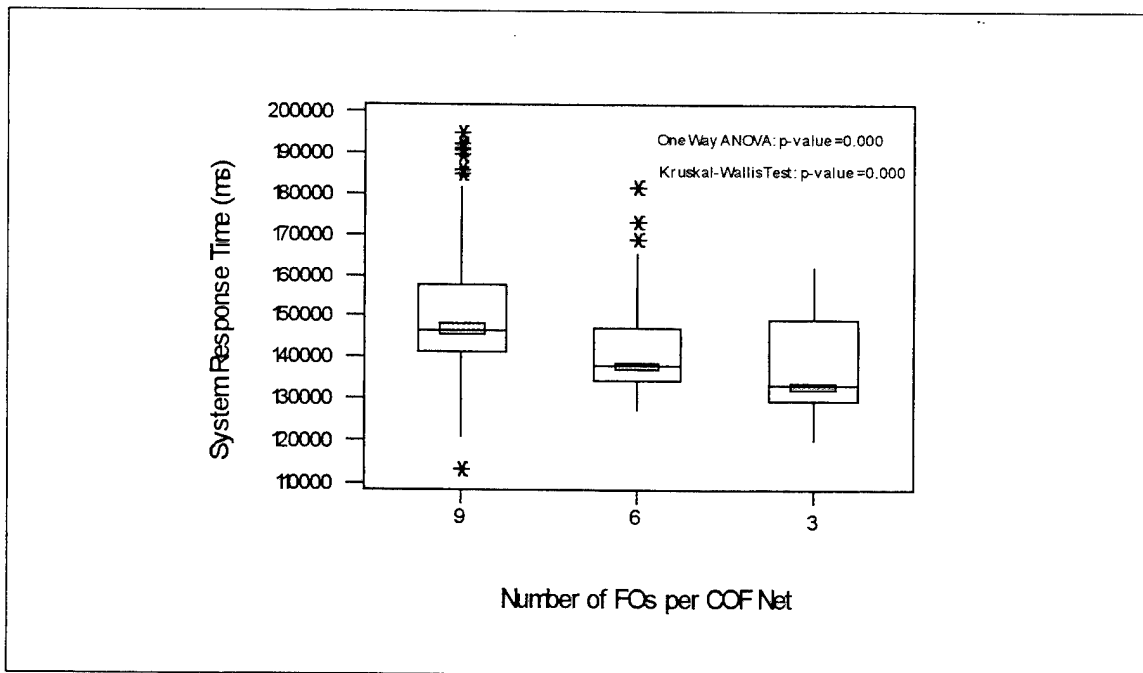
Figure 15. System Response Time By Number Of FOs Per Net
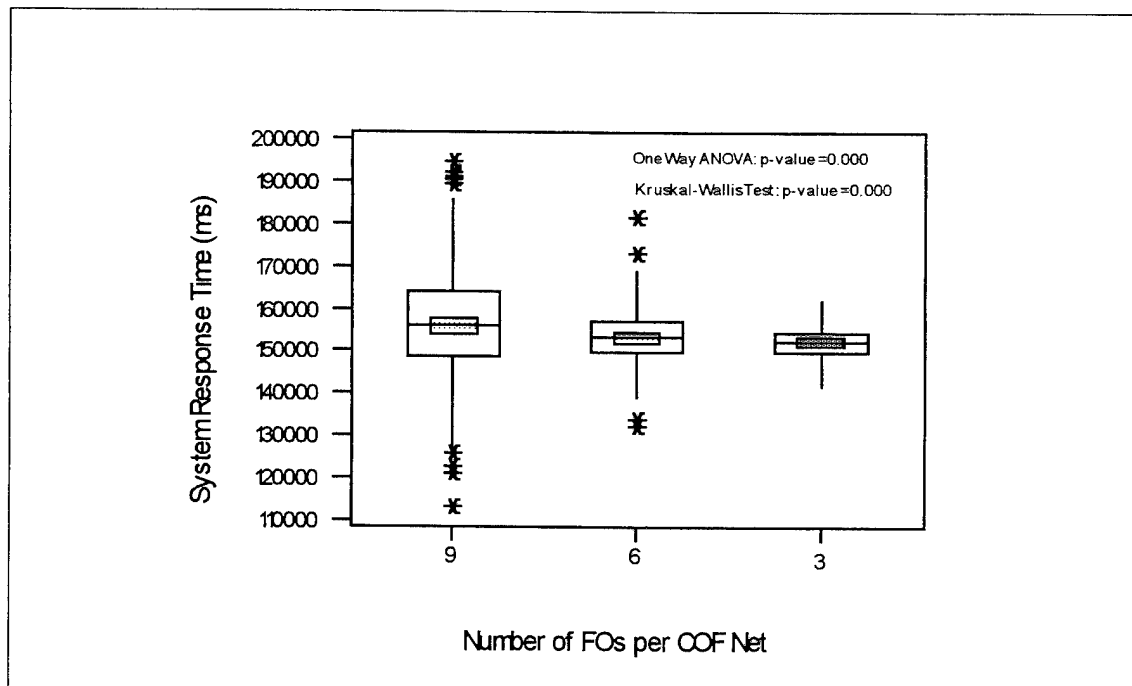
Figure 16. 1200 BPS System Response Time By Number of FOs Per Net
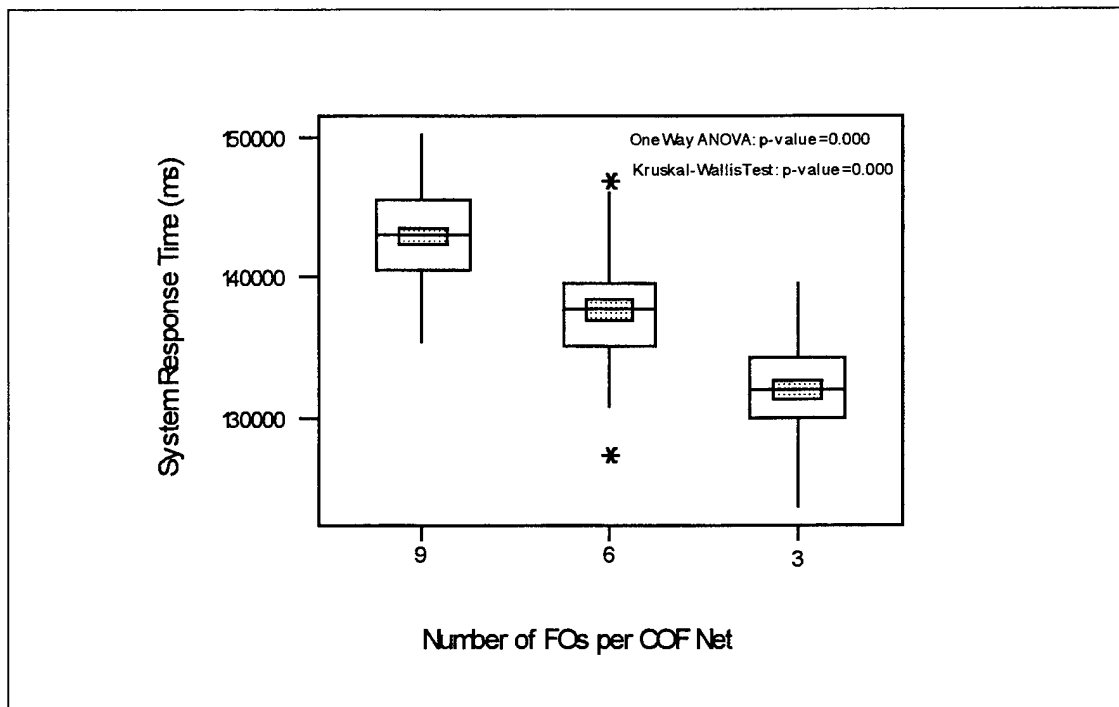
Figure 17. 4800 BPS System Response Time By Number Of FOs Per Net
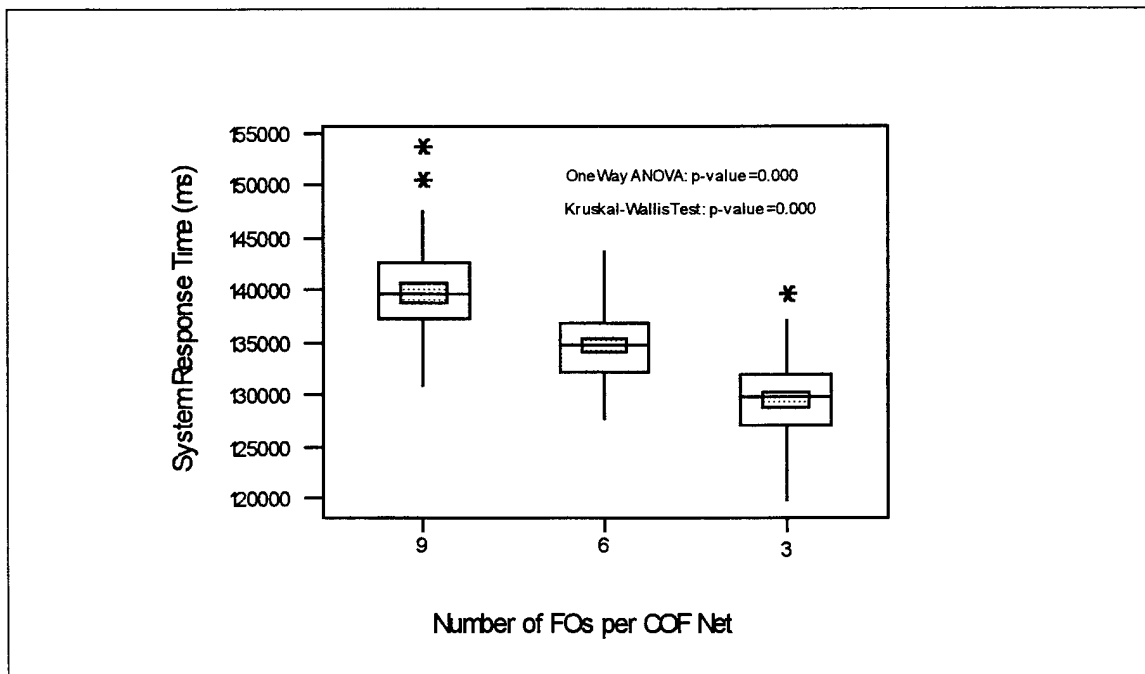
Figure 18. 8000 BPS System Response Time By Number Of FOs Per Net

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Figure 20 shows the box plots for the nine FOs per net response times. The statistic tests yield (p-values = 0.000) suggests that there is a significant difference in the means of the system response times. However, a closer look at the box plots show an overlap of the 95% confidence interval boxes between the 4800 and 8000 bps. This overlap is confirmed by the 95% for mean based on pooled standard deviation and Tukey's pairwise comparison. Thus, the null hypothesis of equal medians and means for the 1200 bps and the other transmission rates can be rejected but the null hypothesis of equal medians and means for the 4800 and the 8000 bps cannot be rejected.

Figures 21 and 22 show the box plots and p-values for the six and three FO per net response times. The 95% confidence interval boxes and p-values of zero from the statistical tests rejects the null hypothesis of equal medians and means for the three transmission rates. Looking back at Figures 20, 21, and 22, it is apparent that the spread of the bulk of the system response times for the 4800 and 8000 bps are much lower than system response times for the 1200 bps transmission rate.
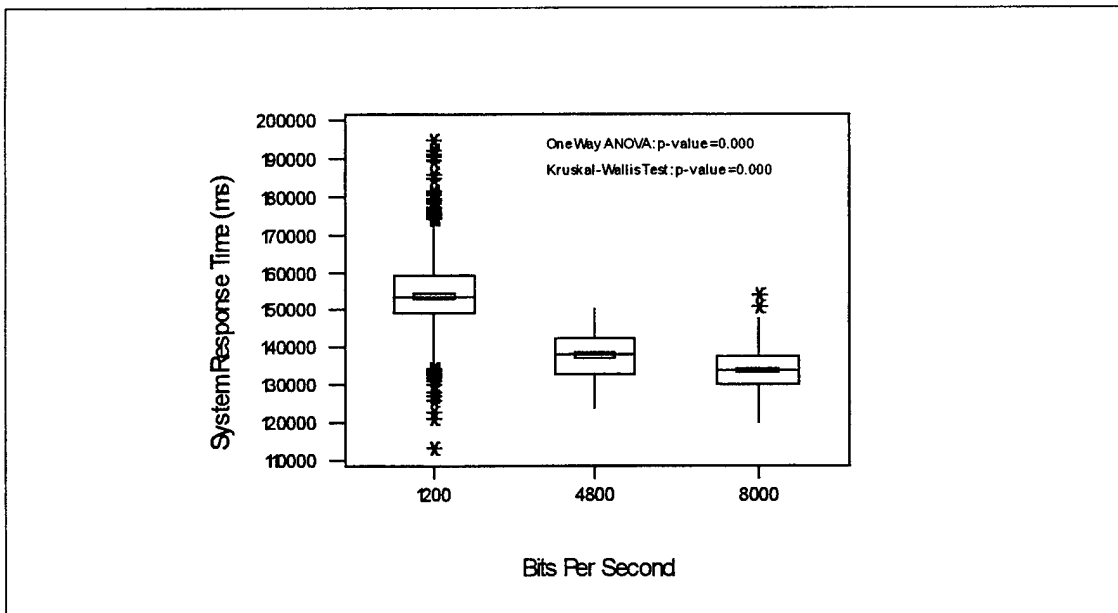
Figure 19. System Response Time By Transmission Rate (all nets)
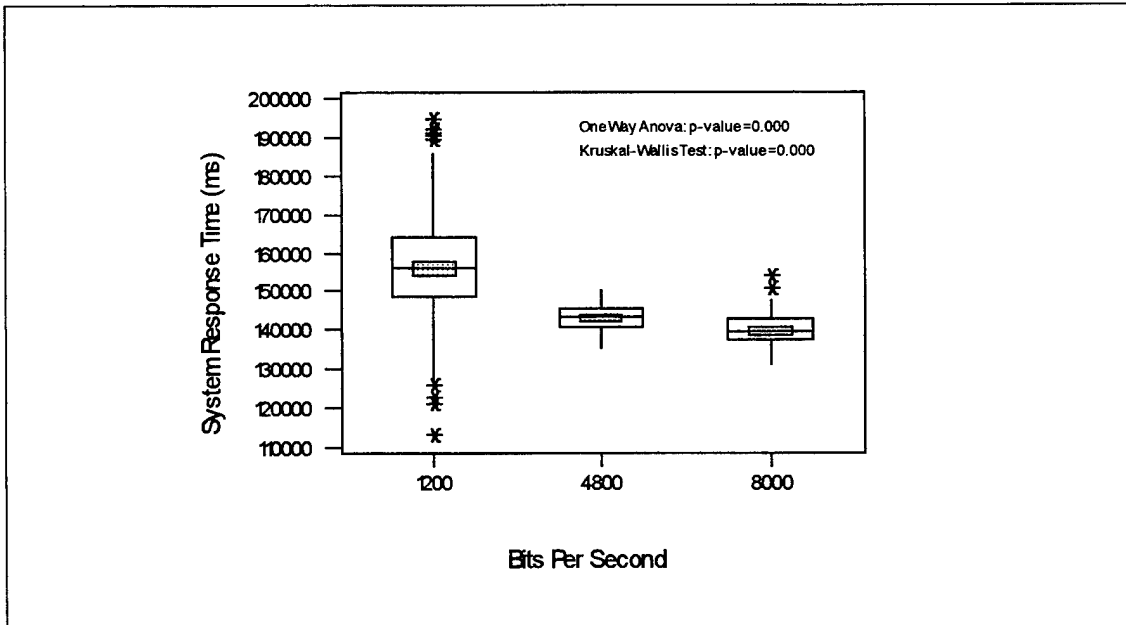
Figure 20. Nine FOs Per Net System Response Time By Transmission Rate
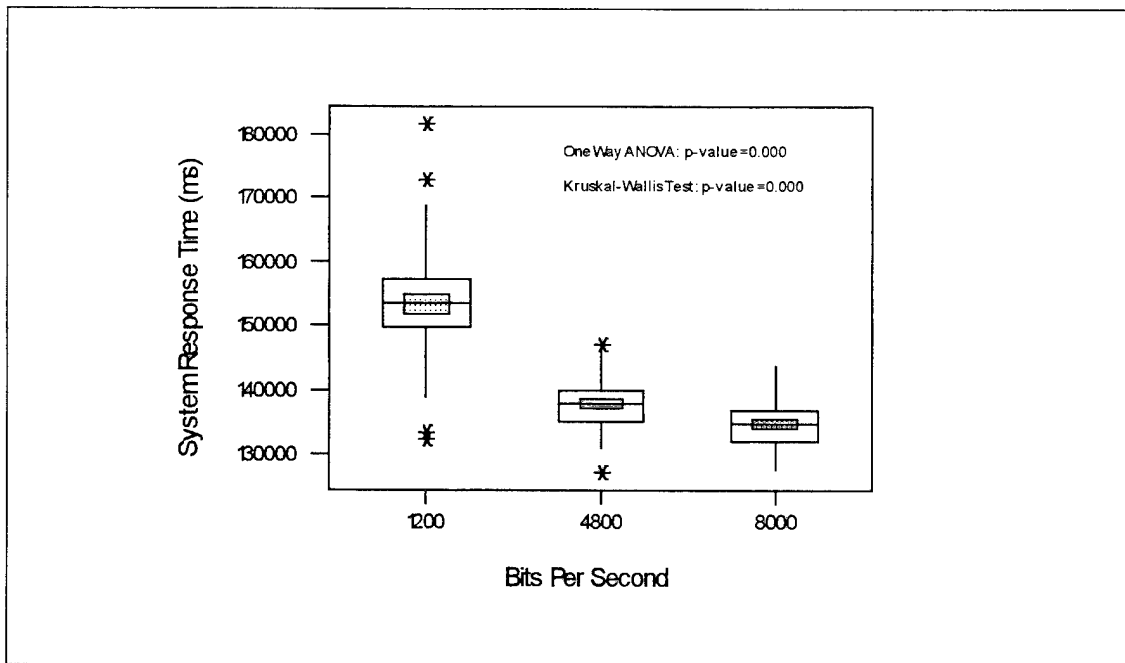
Figure 21. Six FOs Per Net System Response Time By Transmission Rate
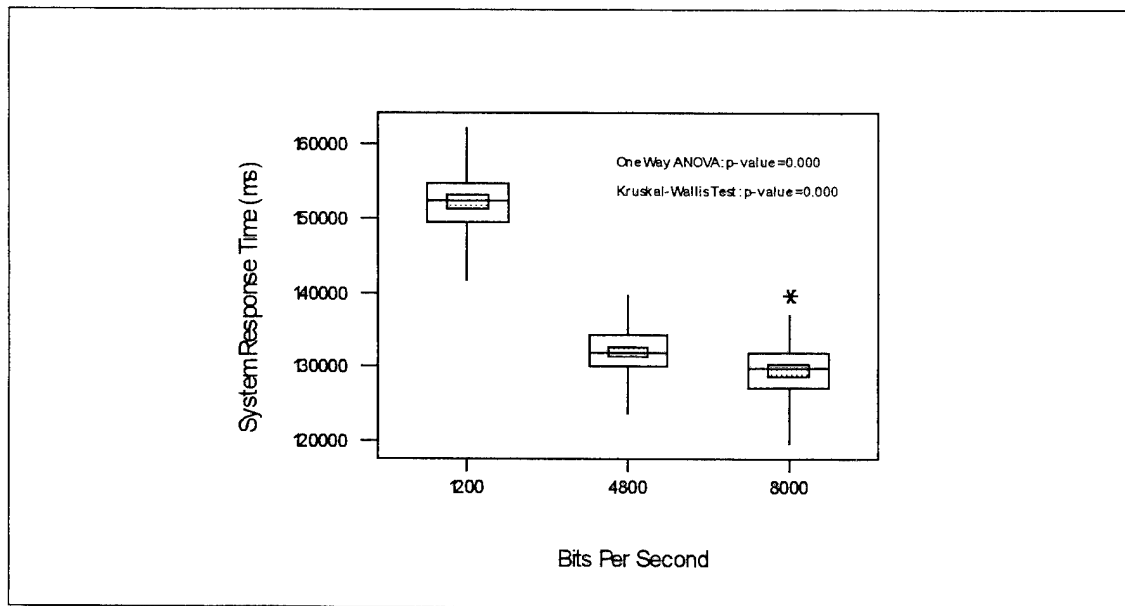
Figure 22. Three FOs Per Net System Response Time By Transmission Rates

50

V. SUMMARY, CONCLUSIONS, RECOMMENDATIONS

A. MODEL AND ANALYSIS SUMMARY

In this study, a simulation model was designed and implemented using COMNET III, a commercial simulation package. The simulation model provided a tool to evaluate fire support responsiveness in the proposed MAGTF C4I concept. Using the average system response times as a measure of responsiveness, the evaluation was accomplished by running nine variations of the model under different transmission rates and number of FOs per COF net in the artillery battalion.

The first phase of the analysis determined the layout of the data for the two-way ANOVA. Once the layout was determined, an ANOVA was performed to test for significant interactions between the two factors. Since the effects were found to be additive (i.e., no significant interactions), it was appropriate to test for significant main effects. A second ANOVA to test for main effects showed significant effects from the two factors. The coefficients of the mathematical model and the main effect plot revealed a significant difference between the 1200 bps and the other two transmission rates (4800 and 8000 bps).

The main effects were further investigated by comparing system response times at different levels of the two factors. This analysis also found a significant difference between 1200 bps and the other two transmission rates. Additionally, it was found that the effects of the number of FOs per COF net were more significant than transmission rates in the Tactical Data Network model (4800 and 8000 bps).

B. CONCLUSIONS

In order to improve the warfighting capability of forces, the Marine Corps is developing systems to assists the MAGTF commanders face unprecedented challenges in exercising command and control in the modern battlefield. These C2 systems and communications are integrated under the MAGTF C4I concept. Implementation of this concept will assist the commanders in the battlefield by providing the capability to keep up with the higher tempo of operations, effectively manage an expanded area of interest, and efficiently handle larger volume of information.

The purpose of this thesis was to design and implement a simulation model to answer the following question: Will the MAGTF C4I concept, the integration of the Tactical Data Network and the C2 Tactical Data Systems, significantly improve the responsiveness of fire support available to maneuver commanders?

The following are conclusions based on the study conducted and the results from the simulation:

1. The MAGTF C4I concept will significantly improve the responsiveness of fire support available to maneuver commanders.

2. In the TDN communications architecture, the number of COF nets (i.e., the number of FOs per net) has more effect than transmission rates on average system response times. Thus, a combined COF net configuration should not be used for an infantry battalion that is expected to be heavily engaged.

3. The difference in average system response times in the TDN model (4800 and 8000 bps transmission rate) was found to be statistically significant; however, the difference between the means (approximately 3 seconds) is insignificant in an operational environment.

C. RECOMMENDATIONS

Implementation of the MAGTF C4I concept will transform the Marine Corps communications architecture from a network of dedicated voice channels into a system of information pipelines connecting various elements of the MAGTF. The ease of this evolution will depend not only on the successful fielding of the hardware and software components, but also on developing appropriate techniques and procedures for digital operations. Each functional area should review and revise, if necessary, their operating procedures to fully exploit the capabilities of the C2 systems.

This thesis evaluated a fraction of the MAGTF C4I concept. There remains much work to be done in evaluating the MAGTF C4I concept. The Marine Corps should increase its effort in simulation modeling to assess different design alternatives of proposed systems and procedures before they are implemented.

The accuracy of a simulation model is highly dependent on realistic data available to estimate the characteristics of the real system. Therefore, in order to have accurate data available, the Marine Corps should begin collecting data for future modeling and simulation during field operations where fielded C2 systems are employed.

APPENDIX A. COMNET III GRAPHICS AND SAMPLE OUTPUT

The following figures show examples of subnetworks used in the COMNET III simulations models.
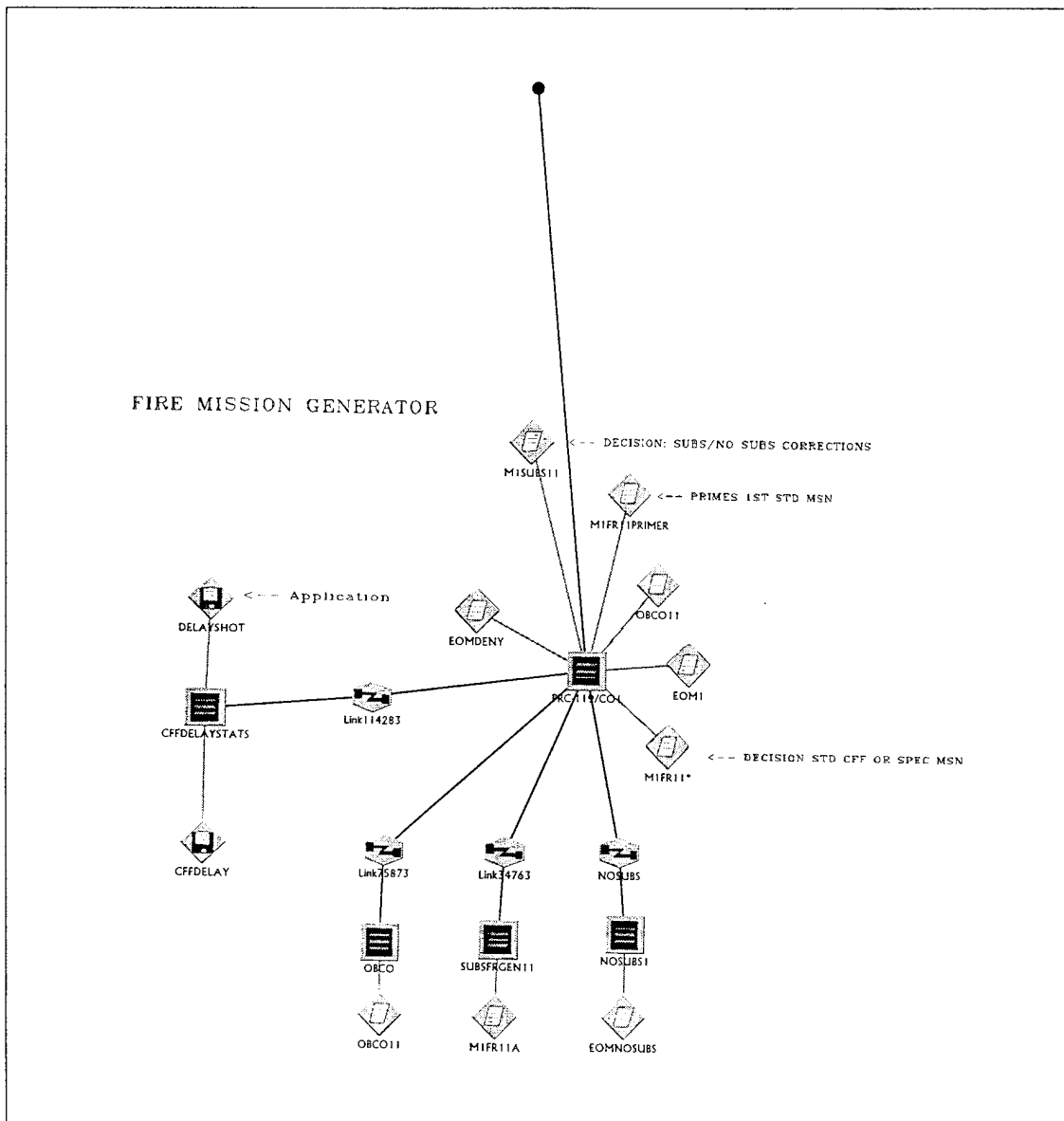
Figure 23. Fire Mission Generator/Forward Observer
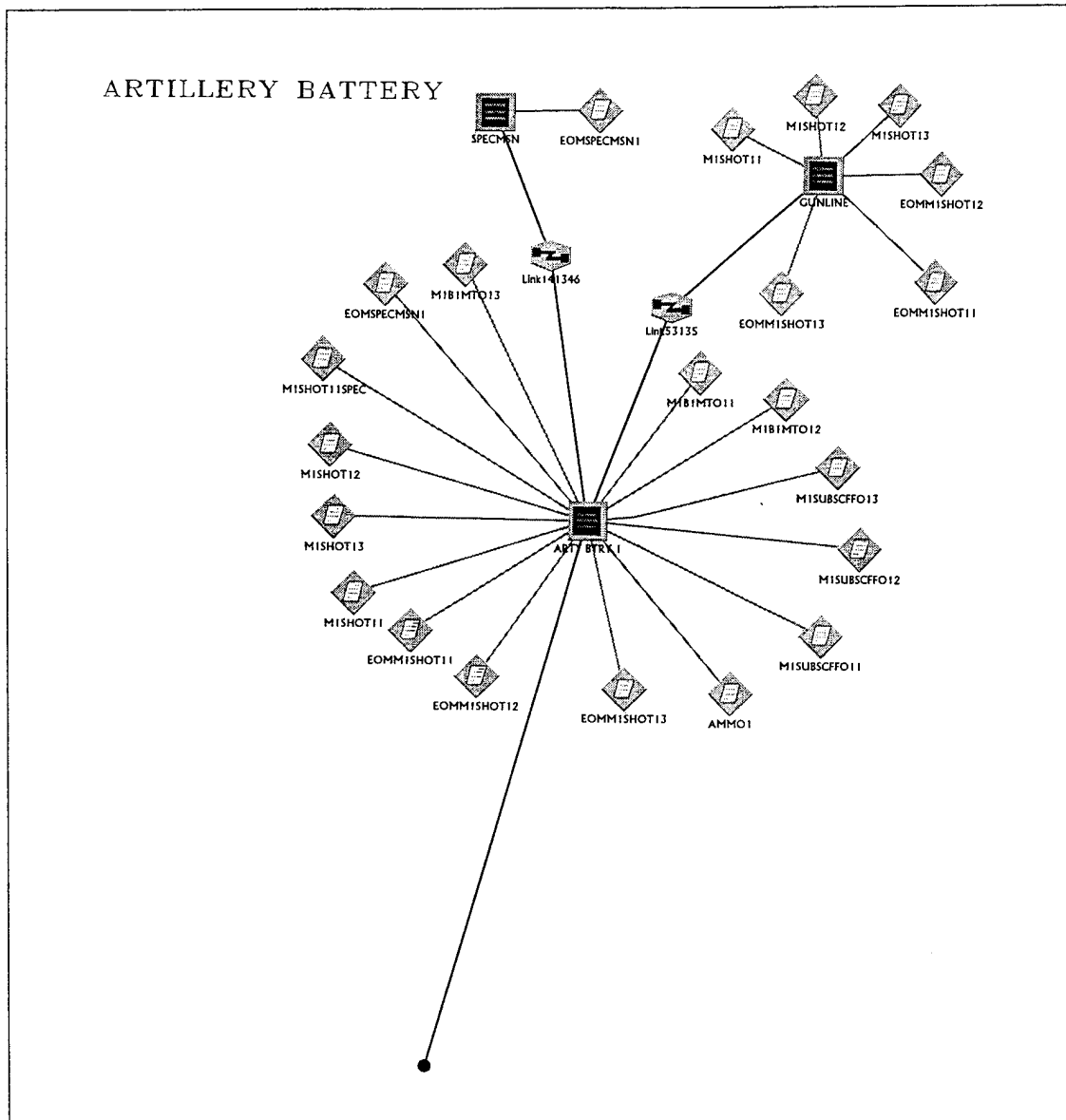
Figure 24. Artillery Battery
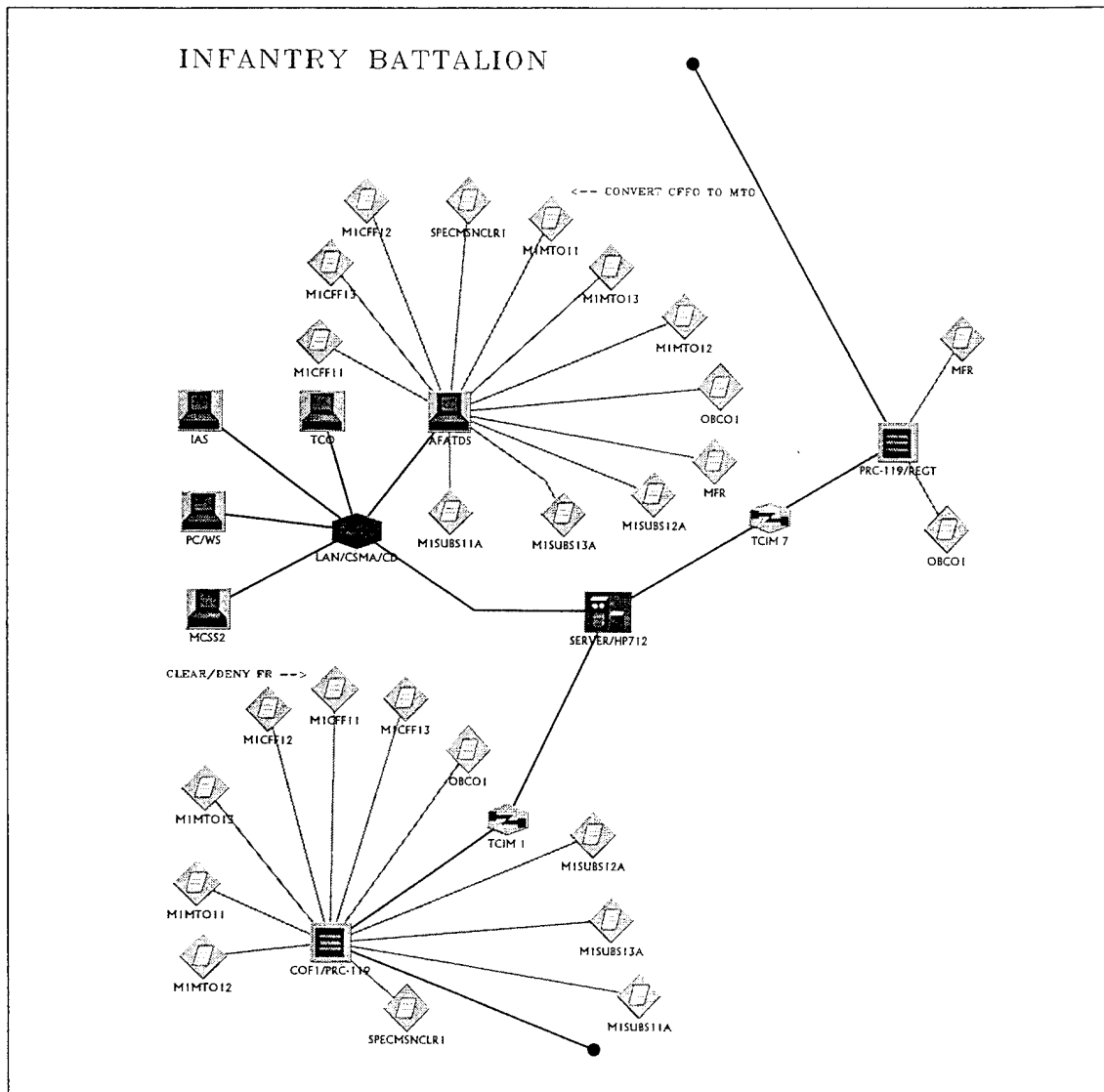
Figure 25. Infantry Battalion C2 Facility
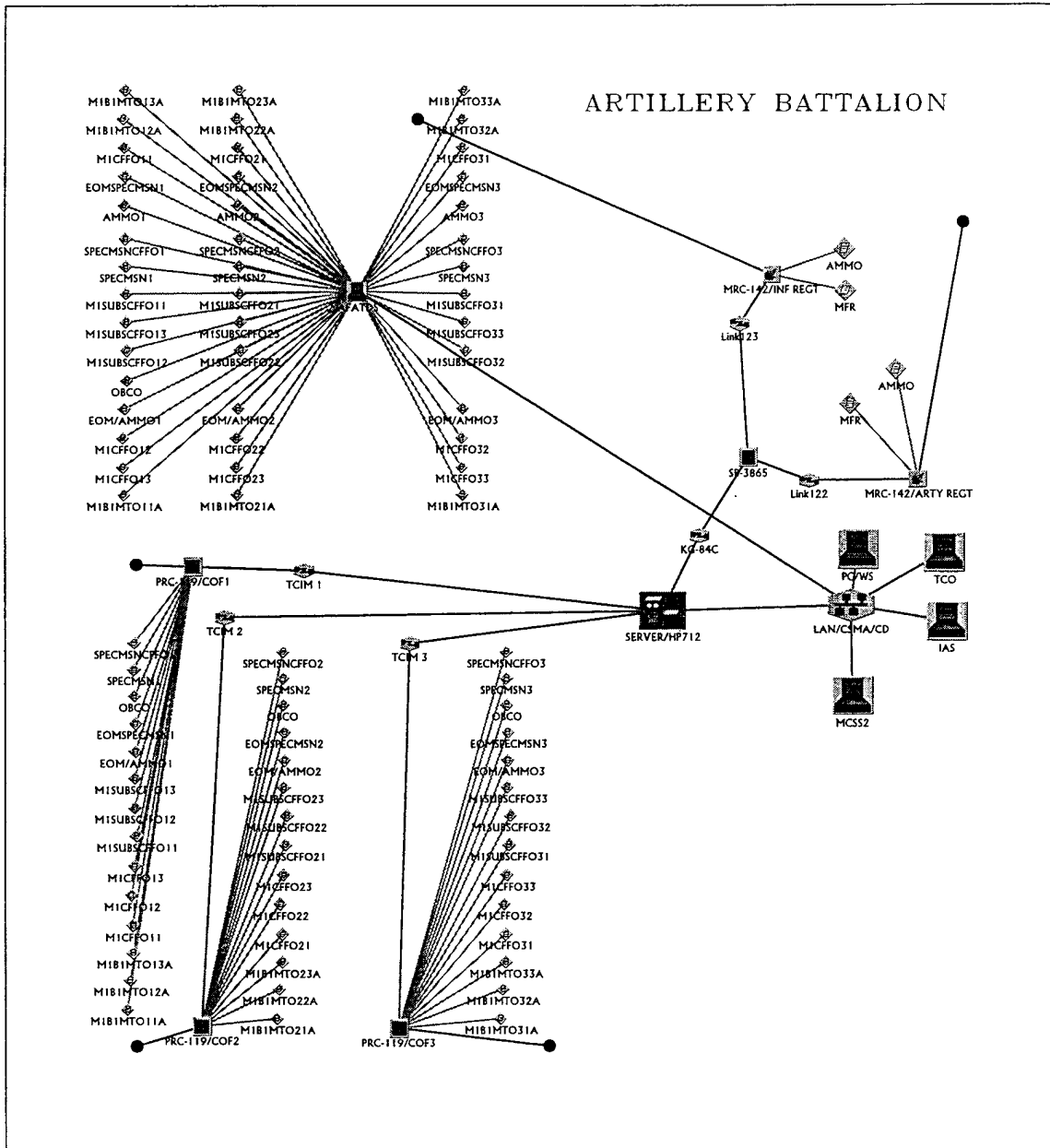
Figure 26. Artillery Battalion FDC

APPENDIX B. RESULTS OF STATISTICAL ANALYSIS

This appendix contain the results of the statistical tests performed in Chapter IV.

Statistical Test Results for Figure 6

Analysis of Variance on T12-6VS3

Source	DF	SS	MS	F	p
S12-6VS3	1	114605096	114605096	2.57	0.112
Error	124	5.538E+09	44663408		
Total	125	5.653E+09			

Mann-Whitney Confidence Interval and Test

12COF2W6 N = 84   Median =   153459
12COF2W3 N = 42   Median =   151750
Point estimate for ETA1-ETA2 is   1904
95.0 Percent C.I. for ETA1-ETA2 is (-122,3879)
W = 5691.0
Test of ETA1 = ETA2 vs. ETA1 ~= ETA2 is significant at 0.0650
Cannot reject at alpha = 0.05

Statistical Test Results for Figure 7

Analysis of Variance on T48-6VS3

Source	DF	SS	MS	F	p
S48-6VS3	1	849934464	849934464	71.22	0.000
Error	124	1.480E+09	11934220		
Total	125	2.330E+09			

Mann-Whitney Confidence Interval and Test

48COF2W6 N = 84   Median =   137768
48COF2W3 N = 42   Median =   132411
Point estimate for ETA1-ETA2 is   5580
95.0 Percent C.I. for ETA1-ETA2 is (4297,6822)
W = 6639.0
Test of ETA1 = ETA2 vs. ETA1 ~= ETA2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

Statistical Test Results for Figure 8

Analysis of Variance on T80-6VS3

```
Source      DF    SS         MS         F       p
S80-6VS3    1     1.196E+09  1.196E+09  120.30  0.000
Error       169   1.681E+09  9944934
Total       170   2.877E+09
```

Mann-Whitney Confidence Interval and Test

```
80COF2W6  N = 114    Median =    134627
80COF2W3  N =  57    Median =    129058
```
Point estimate for ETA1-ETA2 is   5439
95.0 Percent C.I. for ETA1-ETA2 is (4462,6486)
W = 12386.0
Test of ETA1 = ETA2 vs. ETA1 ~= ETA2 is significant at 0.0000

Statistical Test Results for Figure 9

Analysis of Variance on T12-3/N

```
Source     DF    SS         MS        F      p
S12-3/N    1     25007600   25007600  1.65   0.201
Error      148   2.245E+09  15169894
Total      149   2.270E+09
```

Mann-Whitney Confidence Interval and Test

```
T12-3/N   N = 150    Median =    152476
S12-3/N   N = 150    Median =       3
```
Point estimate for ETA1-ETA2 is   152473
95.0 Percent C.I. for ETA1-ETA2 is (151634,152951)
W = 33825.0
Test of ETA1 = ETA2 vs. ETA1 ~= ETA2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

Statistical Test Results for Figure 10

Analysis of Variance on T48-3/N

Source	DF	SS	MS	F	p
S48-3/N	1	467408	467408	0.05	0.828
Error	121	1.190E+09	9834628		
Total	122	1.190E+09			

Mann-Whitney Confidence Interval and Test

T48-3/N   N = 123   Median =   131989
S48-3/N   N = 123   Median =   3
Point estimate for ETA1-ETA2 is   131986
95.0 Percent C.I. for ETA1-ETA2 is (131322,132652)
W = 22755.0
Test of ETA1 = ETA2 vs. ETA1 ~= ETA2 is significant at 0.0000
The test is significant at 0.0000 (adjusted for ties)

Statistical Test Results for Figure 11

Analysis of Variance on T802-3/N

Source	DF	SS	MS	F	p
S802-3/N	1	16856848	16856848	1.50	0.222
Error	181	2.031E+09	11219906		
Total	182	2.048E+09			

Mann-Whitney Confidence Interval and Test

80COF2W3 N = 57   Median =   129058
8000COF3 N = 126   Median =   129922
Point estimate for ETA1-ETA2 is   -615
95.0 Percent C.I. for ETA1-ETA2 is (-1712,460)
W = 4863.0
Test of ETA1 = ETA2 vs. ETA1 ~= ETA2 is significant at 0.2515
Cannot reject at alpha = 0.05

General Linear Model With Interactions

Factor   Levels Values
BPS   3 1200 4800 8000
NUM-NETS   3   1   2   3

Analysis of Variance for TIME

Source	DF	Seq SS	Adj SS	Adj MS	F	P
BPS	2	8023818752	5539813376	2769906688	95.47	0.000
NUM-NETS	2	871641152	668488768	334244384	11.52	0.000
BPS*NUM-NETS	4	88298000	88298000	22074500	0.76	0.551
Error	1278	3.7079E+10	3.7079E+10	29013258		
Total	1286	4.6063E+10				

General Linear Model Without Interactions

Factor   Levels Values
BPS   3 1200 4800 8000
NUM-NETS   3   1   2   3

Analysis of Variance for TIME

Source	DF	Seq SS	Adj SS	Adj MS	F	P
BPS	2	8023818752	5639720960	2819860480	97.26	0.000
NUM-NETS	2	871641152	871641152	435820576	15.03	0.000
Error	1282	3.7167E+10	3.7167E+10	28991608		
Total	1286	4.6063E+10				

Means for Average Response Times

BPS	Mean	Stdev
1200	154120	579.9
4800	137702	1804.1
8000	135215	1493.7

NUM-NETS		
1	145651	908.2
2	142678	1089.5
3	138707	1296.2

Statistical Test Results for Figure 15

Analysis of Variance on TIME

Source	DF	SS	MS	F	p
NUM-NETS	2	3.798E+10	1.899E+10	149.59	0.000
Error	1284	1.630E+11	126934288		
Total	1286	2.010E+11			

Kruskal-Wallis Test

LEVEL	NOBS	MEDIAN	AVE. RANK	Z VALUE
1	549	146550	833.6	15.79
2	282	137838	587.2	-2.90
3	456	132918	450.8	-13.81
OVERALL	1287		644.0	

H = 272.66 d.f. = 2 p = 0.000

Statistical Test Results for Figure 16

Analysis of Variance on 1200

Source	DF	SS	MS	F	p
SCOF1	2	1.851E+09	925560320	8.35	0.000
Error	537	5.955E+10	110888872		
Total	539	6.140E+10			

Kruskal-Wallis Test

LEVEL	NOBS	MEDIAN	AVE. RANK	Z VALUE
1	306	156124	295.5	4.26
2	84	153459	257.1	-0.86
3	150	152476	226.9	-4.02
OVERALL	540		270.5	

H = 20.19 d.f. = 2 p = 0.000
H = 20.19 d.f. = 2 p = 0.000 (adjusted for ties)

Statistical Test Results for Figure 17

Analysis of Variance on 4800

Source	DF	SS	MS	F	p
S4800	2	7.220E+09	3.610E+09	321.83	0.000
Error	330	3.701E+09	11216616		
Total	332	1.092E+10			

```
                                 Individual 95% CIs For Mean
                                 Based on Pooled StDev
 Level    N    Mean   StDev  ----+---------+---------+---------+--
   1     126  142972   3425                                (*-)
   2      84  137625   3548                   (-*-)
   3     123  132201   3124 (-*)
                              ----+---------+---------+---------+--
 Pooled StDev =   3349            133000   136500   140000   143500
```

Tukey's pairwise comparisons

Family error rate = 0.0500
Individual error rate = 0.0197
Critical value = 3.31
Intervals for (column level mean) - (row level mean)

```
            1          2

   2      4242
          6450


   3      9777      4314
         11764      6533
```

Kruskal-Wallis Test

LEVEL	NOBS	MEDIAN	AVE. RANK	Z VALUE
1	126	143048	257.4	13.37
2	84	137768	168.0	0.11
3	123	131989	73.7	-13.53
OVERALL	333		167.0	

$H = 226.50$ d.f. $= 2$ $p = 0.000$
$H = 226.50$ d.f. $= 2$ $p = 0.000$ (adjusted for ties)

Statistical Test Results for Figure 18

Analysis of Variance on 8000

Source	DF	SS	MS	F	p
S8000	2	7.749E+09	3.875E+09	328.52	0.000
Error	411	4.847E+09	11793927		
Total	413	1.260E+10			

Kruskal-Wallis Test

LEVEL	NOBS	MEDIAN	AVE. RANK	Z VALUE
1	117	139568	337.3	13.85
2	114	134627	232.2	2.59
3	183	129726	109.1	-14.89
OVERALL	414		207.5	

H = 266.27 d.f. = 2 p = 0.000
H = 266.27 d.f. = 2 p = 0.000 (adjusted for ties)

Statistical Test Results for Figure 19

Analysis of Variance on TIME

Source	DF	SS	MS	F	p
BPS	2	1.160E+11	5.802E+10	877.34	0.000
Error	1284	8.492E+10	66133912		
Total	1286	2.010E+11			

Kruskal-Wallis Test

LEVEL	NOBS	MEDIAN	AVE. RANK	Z VALUE
1200	540	153579	980.8	27.64
4800	333	137884	479.3	-9.39
8000	414	133680	337.1	-20.40
OVERALL	1287		644.0	

H = 791.22 d.f. = 2 p = 0.000

Statistical Test Results for Figure 20

Analysis of Variance on COF1

```
Source  DF   SS        MS        F      p
SCOF1    2  2.978E+10  1.489E+10  146.50  0.000
Error   546  5.549E+10  101621384
Total   548  8.526E+10
```

```
                              Individual 95% CIs For Mean
                              Based on Pooled StDev
Level  N    Mean   StDev  ----------+---------+---------+------
1200  306  156234  13107                                (*-)
4800  126  142972  3425       (--*--)
8000  117  140000  3739 (--*--)
                              ----------+---------+---------+------
Pooled StDev =   10081          144000  150000  156000
```

Tukey's pairwise comparisons

Family error rate = 0.0500
Individual error rate = 0.0194
Critical value = 3.31
Intervals for (column level mean) - (row level mean)

```
         1200      4800

4800    10765
        15760


8000    13669    -58
        18798    6001
```

Kruskal-Wallis Test

```
LEVEL  NOBS   MEDIAN  AVE. RANK  Z VALUE
1200   306   156124    366.9    15.24
4800   126   143048    191.1    -6.76
8000   117   139568    124.9   -11.54
OVERALL 549            275.0
H = 242.88  d.f. = 2  p = 0.000
H = 242.88  d.f. = 2  p = 0.000 (adjusted for ties)
```

Statistical Test Results for Figure 21

Analysis of Variance on COF2

```
Source    DF    SS          MS        F       p
SCOF2     2   1.839E+10   9.195E+09  361.20   0.000
Error     279 7.103E+09   25457230
Total     281 2.549E+10
```

Kruskal-Wallis Test

```
LEVEL    NOBS   MEDIAN  AVE. RANK  Z VALUE
 1200     84    153459    235.5    12.60
 4800     84    137768    128.7    -1.72
 8000    114    134627     81.7    -10.15
OVERALL  282             141.5
```
H = 174.91 d.f. = 2 p = 0.000
H = 174.91 d.f. = 2 p = 0.000 (adjusted for ties)

Statistical Test Results for Figure 22

Analysis of Variance on COF3

```
Source    DF    SS          MS        F       p
SCOF3     2   4.672E+10   2.336E+10  1921.17  0.000
Error     453 5.508E+09   12159534
Total     455 5.223E+10
```

Kruskal-Wallis Test

```
LEVEL    NOBS   MEDIAN  AVE. RANK  Z VALUE
 1200    150    152476    381.5    17.36
 4800    123    131989    191.6    -3.64
 8000    183    129726    127.9    -13.34
OVERALL  456             228.5
```
H = 318.46 d.f. = 2 p = 0.000

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